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- Forty Years of Astronomy. By Sir Arthur Eddington
- The Treshnish Isles. By F. Fraser Darling
- New Hearts for Old. By John Yudkin
- The Problem of the Lunar Craters
- Harnessing the Victoria Falls

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The Problem of the Lunar Craters

By C. G. JAMES

(*In this article Mr James sets out one of the most interesting questions about the moon: how were the lunar craters formed? He describes several of the most strongly held theories, and also various attempts to reproduce lunar scenery in the laboratory. His own photomicrographs of welded steel make a most striking analogy to some lunar photographs.*)

IN 1608, Hans Lippershey, a spectacle-maker of Middelburgh, Holland, constructed a crude telescope. The discovery was momentous, for when the news reached Galileo, the Florentine made his own much improved "optic tube" from, it is said, an old organ pipe and a couple of spectacle lenses. Directing his telescope to the moon Galileo saw for the first time the lunar mountains, "seas", and the saucer-shaped formations with encircling walls which were afterwards named ring mountains or craters.

Astronomers following Galileo have been intrigued—and not a little bewildered—at the complexity of the lunar scenery and the problem it presents. Many and varied are the theories that attempt to explain the origin of the so-called craters and similar formations. Perhaps the new 200-inch reflector soon to be erected on Mount Palomer will help to a solution, but until then astronomers must depend on existing equipment.

It is not often realized, however, that portions of the moon are better known than some parts of the earth. The maps of selenographers like Beer and Madler, Schmidt, Nasmyth, Proctor, Neison, and Goodacre show an astonishing amount of detail. The examination of these maps, allied with the excellent lunar photographs now to be obtained, can be exciting. With the modest help of a small telescope the study becomes a fascinating adventure, for many of the larger formations can be readily detected.

A moderately good telescope will show that the moon has the following outstanding types of scenery, of which, first, the "maria" or "seas" are the most noticeable. They are large, dark, and comparatively plain areas. They are obviously not seas in the accepted sense as the moon has neither water nor air.

Secondly, there are mountains and ranges very similar to terrestrial types except that they are more rugged and steep in proportion to the moon's size than those of the earth.

Thirdly, there is the most mystifying of lunar phenomena—the walled plains, ring mountains and craters. These vary in size from a mile or less in diameter (which some call craters proper) up to the huge walled plains over one hundred miles across with encircling mountains which may be anything up to 30,000 ft. in height. In many cases the varying types overlap; in others the plains may be pitted by small craters. Every type has been detected in, as it were, all stages of growth, some being nearly perfect while others give only a suspicion of their presence. Some have central peaks rising from their floor, a few of these peaks having a small elevation crater. In most cases these central peaks or cones are not so high as the surrounding mountain wall. Other varieties of craters have rough floors and no peak, the internal floor being strewn with what appear to be huge boulders. Still other types have smooth floors and these are generally of a darker hue than those with rougher floors or peaks. The greater number of the ring formations have floors which are much lower than the terrain outside the encircling wall, the depth of the floor, in some cases, being nearly three times the height of the mountains measured from the average surface.

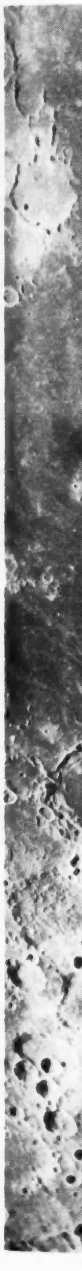
These ring-shaped structures occur in their greatest number in the southern portion of the moon. The largest number are of the small type; as the size increases so the numbers decrease.

Other lunar phenomena are the rilles and the rays, the former being cracks in the surface, while the rays are bright broken streaks radiating from some of the largest craters. These are definitely not cracks; they are much brighter when the moon is at the full and they cast no shadow when the light from the sun strikes the surface at an angle.

This, then, is what telescopic examination tells us of the moon's surface, and the ring-shaped structures present, probably, the most fascinating problem for elucidation. No really satisfactory hypothesis of their conception has yet been presented. They are so unlike any geological formation on the same scale on earth. How were they caused? Was the agency external or internal? Did great heat or the lack of it generate them?

Selenologists have proposed three main theories of their formation: (*a*) the volcanic; (*b*) the meteoric; (*c*) the ice or glacial theory. Each of these theories have sub-theories and different methods of interpolation with consequent objections and anomalies.

Now, the volcanic theory is probably the most popular, but how much the theory



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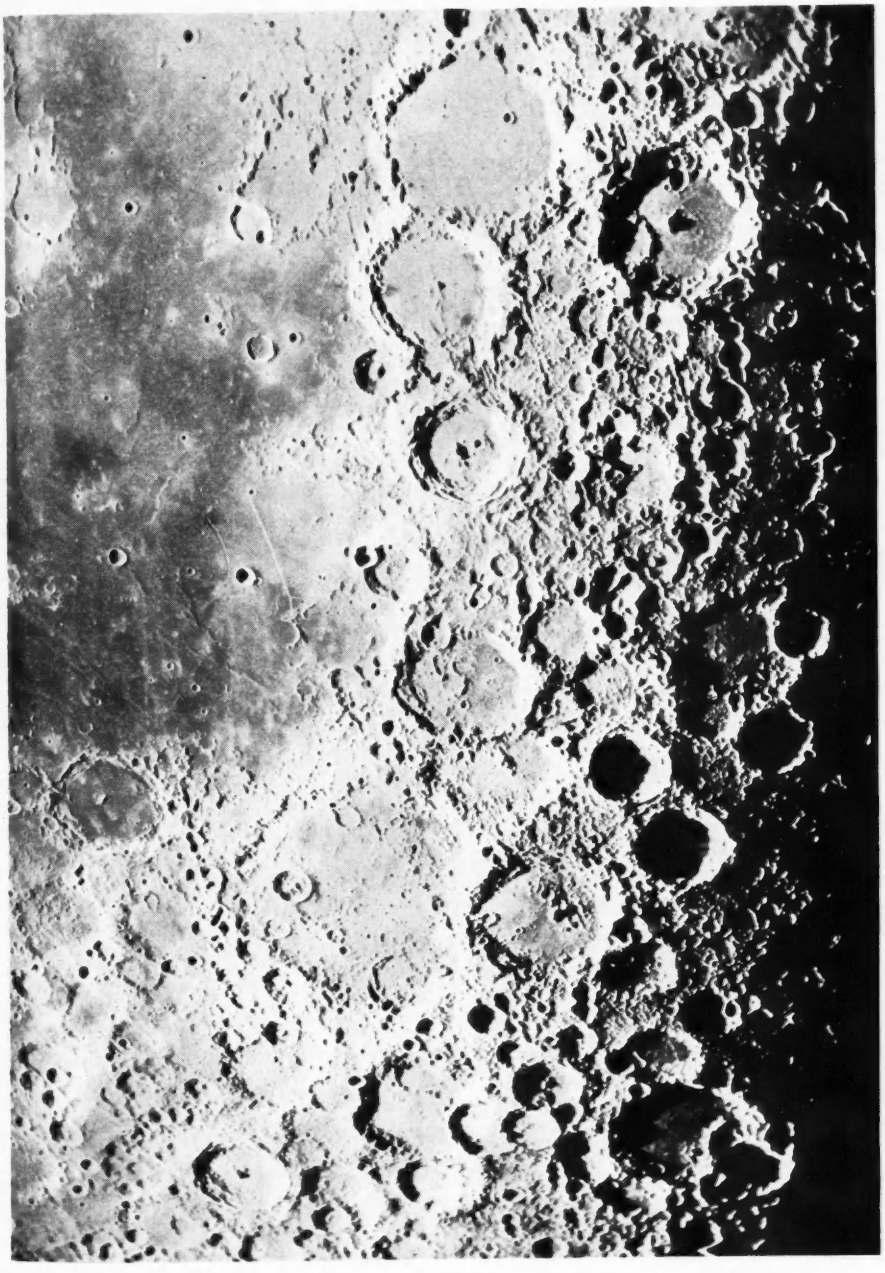


Fig. 1. *Photograph: the Moon, Tycho to Ptolomaeus* (100-*in. reflector, Mt Wilson*)

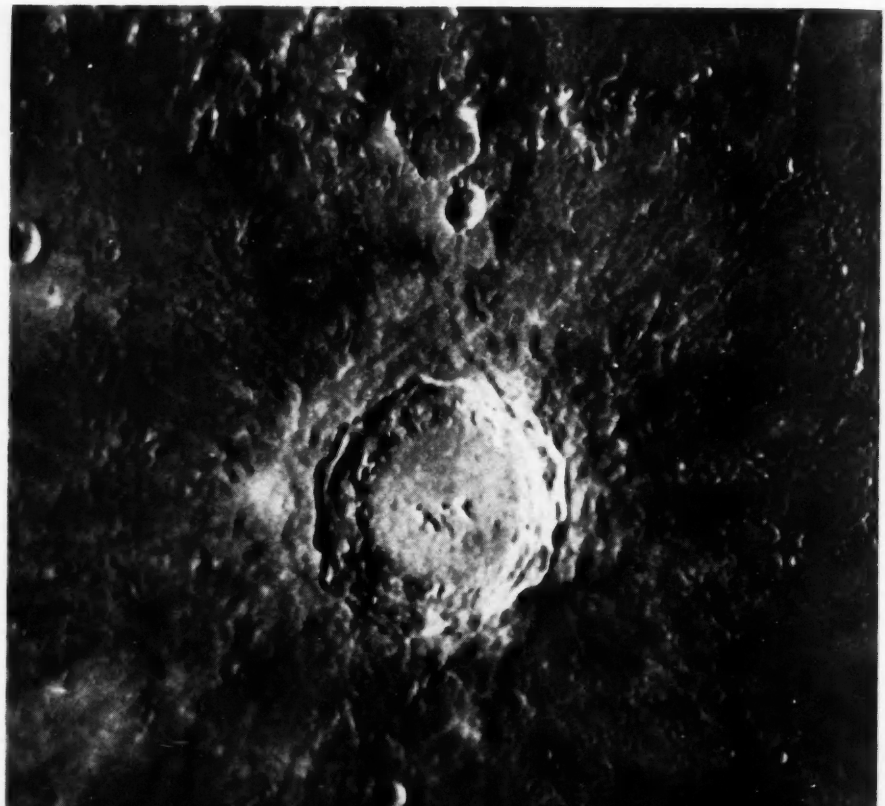


Fig. 2. *Photograph: the Moon, Copernicus* (100-*in. reflector, Mt Wilson*)

owes to the word "crater" is a moot point. Kant did not like the word or the volcanic theory, and Hook also disagreed with the volcanic hypothesis. The younger Herschel, on the other hand, said in regard to the formations that "...they offer in short, in its highest perfection, the true volcanic character, as it may be seen in the crater of Vesuvius, and in a map of the volcanic districts of the Campi Phlegraei or the Puy de Dôme. In some of the principal (craters) decisive marks of volcanic stratification, arising from successive deposits of ejected matter, and evident

indications of lava currents streaming out in all directions, may be clearly traced with powerful telescopes...." Pickering, the modern astronomer, disagrees and echoes many opinions. He says: "No evidence of explosive action of the vesuvian type has been found anywhere on the moon, with the possible exception of the construction of the central peaks of some of the older formations."

An ingenious volcanic theory once current was that primeval and intense volcanic activity on the moon, aided by the reduced gravitational power, threw debris much farther from the central vent than is possible on the earth. Subsequent partial or feebler activity covered the floor, and, in extreme cases, destroyed the central peak or cone. This might account for the great size and characteristic shape of some of the rings. And yet, if this was so, why is the interior plain depressed below the general level of the moon? Did the great weight of the ejected matter force the floor down into the still semi-fluid underlayer of the surface?—for it has been often pointed out that the material that forms the mountain ring is insufficient to fill the cavity. Gifford propounds the pertinent question how volcanic action could be violently explosive, since there is no water or water vapour on the moon. Charles Darwin also pointed this out, and went on to say, in connexion with our own planet's volcanoes, that the characteristic cone is built up by repeated ejections causing an accumulation of materials around the vent; but he also said great craters might be formed or enlarged by the subsidence of the floors after eruptions.

A modification of the volcanic theory, due to Pickering, was that there was no intense volcanic activity but only a slow welling up of lava followed by a subsidence at a later date. But we could go on describing different opinions. All shades can be found mirrored in the general volcanic theory. For instance, there is the bubble theory wherein it was suggested that the craters are the residual rims of giant bubbles caused by internal heat expelling gas through a plastic surface.

The internal heat theories are interesting, but we will leave them and examine the meteoric theory which was first suggested by Proctor and subsequently abandoned by him but not by many others. Drop a stone into a mud bed and a shape approaching that of a lunar crater is formed. Again, an aerial picture of a devastated shell-pitted area appears, at first glance, to possess features akin to the moon. The theory that the lunar rings were formed by impact of bodies from without seems attractive, and it must be confessed that the theory of bombardment of the surface by meteorites was a plausible one. But from what source were the meteorites derived? Were they cosmic fragments left over from the process of planet building when the solar system was born? Or were they, as Tschermak once suggested, ejected from the earth when our volcanic activity was of huge dimensions—ejected with such terrific velocity that they escaped from the earth's gravitational grasp?

There are huge numbers of meteorites still travelling around the solar system. The earth constantly revolving on its axis in its orbit round the sun nets upwards of two million every day. Most are small, as Woolley pointed out in *Discovery* (April 1938), and are vaporized before reaching solid earth. Others, of larger

dimensions, strike the ground. On 30 June 1908, a very large meteorite fell at Yenessei in Russia and laid waste an area of 280 square miles of forest. The meteor crater in Arizona has already been described by Woolley. Still another at Fort Rock, Oregon, is half a mile in diameter and 250 ft. deep!

One of the great objections to the meteoric hypothesis is that all of the craters look as if they were caused by bodies falling normal to the lunar surface. This might be impossible, for some meteorites would have struck at a very oblique angle and thus left long scores. Another objection is the large size of meteorite necessary to form craters over 100 miles in diameter, and again, the number required. An answer to the first objection was proposed by A. C. Gifford, although the original idea was suggested by A. W. Bickerton (Presidential address to the B.A.A. 1915). This reply indicated that a comparatively small meteorite hitting the moon obliquely would generate enormous explosive force and heat. Gifford computed that to make a crater the size of Copernicus, which is 57 miles in diameter, a meteorite 1 mile in diameter (approximately the size of 1937 UB that just missed the earth

Fig. 3. *Photomicrograph. Surface of welded steel.* × 150

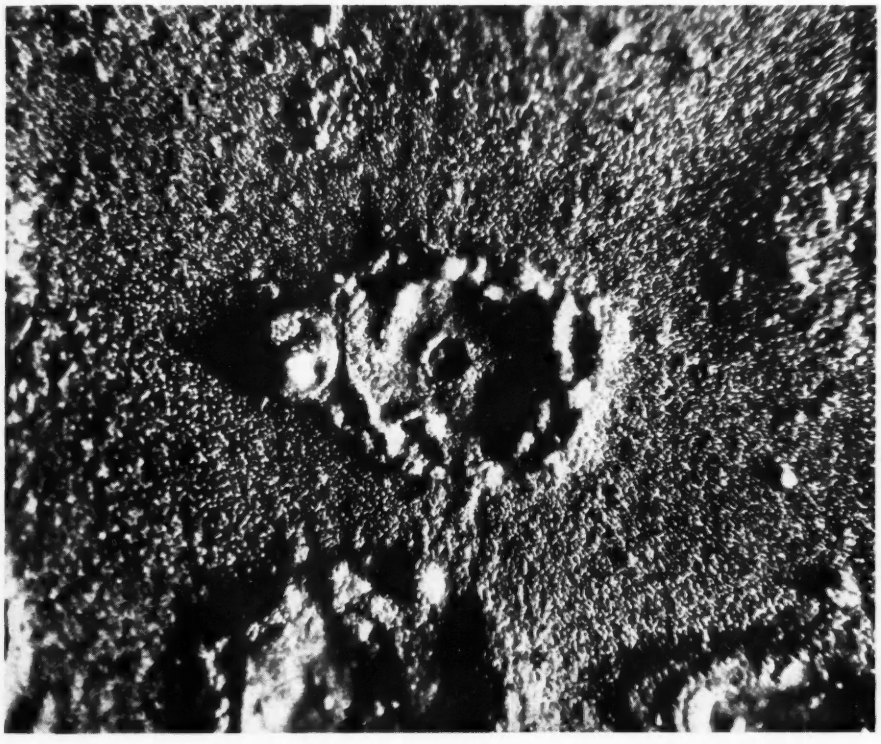


Fig. 4. *Photomicrograph. Welded steel. A crater with central cone and vent.* ×200

last year), travelling with the small astronomical velocity of 40 m.p.s., would be required. On impact the meteorite would generate enough explosive force to eject material at a velocity of 0·17 m.p.s. to the distance required to form the outer mountain wall or ring, the energy per unit mass of the meteorite on being suddenly stopped in its passage through space being 62,500 times that of the ejected debris. The energy of disintegration would be 494,700 calories per gramme, which is *four hundred times the energy of exploding dynamite*! This aspect of the meteoric theory is, perhaps, the best so far.

The ice and glacial theory, or any theory which presupposes that the moon is always covered by snow, must now be abandoned in view of the precise temperature measurements which have been taken at Mount Wilson. These state a temperature of 130° C. on the surface at high lunar noon. Ice accretion from a cosmic source, which was once suggested by P. Fauth, must also be impossible under these circumstances. Still another ice theory propounded by S. E. Peal was that the disappearance of lunar oceans left pools of water which gradually evaporated, the

vapour being deposited as frost and ice around the edges of the pools, thus to make the characteristic crater-like form.

The problem of the lunar craters has induced adherents of various theories to back their claims by attempts to reproduce lunar scenery artificially. Hooke experimented with molten alabaster. Meydenbauer tried the effect of fragments of various substances falling on dust. Gilbert, in 1893, dropped water on to mud, producing craters with rims and central peaks. Bigelow of Boston, U.S.A., fired rifle bullets at plaster of paris. Pickering experimented with melted paraffin wax. Others, like Nasmyth, constructed models. It has also been noted that when iron slag cools it sometimes shows on its surface depressions somewhat similar to the craters of the moon.

Similarities have also been noted in other media. For instance, while engaged on the microscopical examination and investigation of oxy-acetylene welds in thin-gauge mild steel sheet the author of this article was very forcibly struck by the superficial similarity between lunar scenery and the areas in the vicinity of the weld. This is probably the first time the microscope has been used to show such a similarity, and whether the likeness can be helpful in any theory that suggests *external heat* as the cause of the varied lunar phenomena is a matter for interesting speculation. In the case of the microscopic "weld scenery", however, the probable cause of the "craters, cones and walled plains" is that the high temperature of the oxy-acetylene flame (4400° C.) produces an area of molten metal which, on cooling, forms blisters of various kinds. Some of these burst and form the varied forms depicted in the photo-micrographs. Some of the double-walled "craters" may be due to the successive development of bursting and reforming of blisters. The blisters are probably caused by gas eruptions or trapped impurities rendered gaseous, which vent through the molten under-film to form a blister in the surface oxide film. Viewed visually without optical aid, some of the very largest of the formations can be just seen with the naked eye.

But there has always been something lacking in the experiments and similarities described. Either human intervention, dissimilarities or fallacious arguments creep in. The whole subject teems with difficulties and it may well be that the problem will never be solved.

The moon 12½ days old, photographed with a 24-inch telescope

The Moon's Movement in the Sky

By R. v. d. R. Woolley

It is probable that most people are very disappointed when they first look at the heavens through a telescope, but there is one object which never fails to arouse interest and enthusiasm: and that is our nearest neighbour, the moon. The moon also offers considerable opportunity for instruction and amusement to those who do not own a telescope, as its movement is rapid and the object itself cannot fail to be identified. For example, the *full* moon is much higher in the winter sky than in the summer sky.

We can understand the leading features

of the moon's movement if we remember that the moon goes right round the constellations once a month keeping close to the ecliptic. The word ecliptic may sound alarming, but the ecliptic is only the path traced out by the sun in its annual journey round the constellations. Since the midday sun is high in the summer and low in the winter, it follows that that part of the ecliptic which the sun occupies in the summer is the highest above the horizon. Now the full moon is very near to that point in the ecliptic which is directly opposite to the sun, so that the winter full moon occupies roughly the position of the summer sun, and is high above the horizon; while the summer full moon occupies roughly the position of the winter sun and is low in the sky. This phenomenon is very noticeable, if one looks for it.

Another phenomenon to notice is the Harvest moon. In the autumn, the full moon rises at about the same hour on several consecutive nights. The explanation is as follows. The ecliptic being inclined to the equator, the angle which it makes with the horizon varies throughout the day. For example, in midwinter the ecliptic is least inclined to the horizon at midday and most inclined at midnight, as is shown by the low midday sun and high midnight full moon. It follows that the ecliptic is at one or other extreme of inclination at sunset and sunrise in the spring and autumn—halfway between summer and winter—and it happens to be *least* inclined to the horizon at sunset (equals full moon rise) in the autumn. Accordingly, the moon's movement from night to night along the ecliptic makes least difference to its time of rising, and we get the full moon rising at nearly the same time (i.e. twenty minutes apart instead of the normal fifty, in these latitudes) on several consecutive nights. The reverse of this phenomenon is the full moon *setting* on consecutive nights at about the same time, which takes place in the spring. This might properly be called the Milkman's moon.

In the course of its monthly tour round the constellations the moon often passes between the earth and a bright star: such an event is called an occultation. There is only one occultation conspicuous at Greenwich this year, which will take place on 15 September. The bright star ϵ Tauri will be occulted at $22^h\ 32^m$ and will reappear at $23^h\ 07^m$. Last year the moon occulted Mars and so provided a spectacle which many people watched with interest.

If the moon kept severely to the ecliptic we should get the same round of events year after year, but the moon's orbit is inclined by about five degrees to the ecliptic, which means that besides occulting a star such as ϵ Tauri it passes sometimes above it and sometimes below it. It is this departure from the ecliptic which prevents the sun and moon from being eclipsed once a month each. When the moon is full it is opposite the sun, and if the full moon happens to be in the ecliptic it falls in the earth's shadow and is eclipsed: but usually the full moon passes above or below the earth's shadow.

This year there will be a total eclipse of the moon, visible at Greenwich, on 7–8 November. The total phase begins on 7 November at $21^h\ 45^m$ and ends at $23^h\ 07^m$.

During totality the moon assumes a coppery colour, since the only rays from the sun which can reach it and illuminate it are those which are refracted by the earth's atmosphere, and are robbed of their blue components just as the sunset is.

Conversely, when the new moon happens to occur in the ecliptic there is an eclipse of the sun. The apparent size of the moon is almost exactly the same as that of the sun, but an exact fit is a rarity. The distance of the moon from the earth varies slightly (the average distance being a quarter of a million miles) so that the apparent moon is sometimes slightly larger than the sun and sometimes slightly smaller—when there will be no point on the earth's surface at which the eclipse is total. But if the moon's disc is slightly the larger, there will be at any time a small ecliptical area on the earth in which the eclipse is total. This area rushes across the earth as the eclipse pro-

ceeds, making an eclipse track, which may be a hundred or so miles wide: at any one point the eclipse may remain total for several minutes.

The only total eclipse this year took place on 29 May, and it was a poor one, the path of totality being near the South Pole. The only land it crossed was South Georgia, a stormy and cloudy spot in midwinter. No English astronomers had planned to observe this eclipse. The next eclipse which it is intended to observe on a large scale takes place in 1940, the track of totality crossing Brazil and South Africa. There will not be a total eclipse visible in England until 1999.

The moon's movement used to be of the utmost importance to navigators, who need to know Greenwich time in order to determine their longitude. Nowadays they can use wireless time signals, but before the advent of radio navigators had to rely on carrying chronometers. The best check on the ship's chronometers was afforded by the moon's position amongst the stars: one can regard the moon as the hand of a great clock which goes round once a month, its position at any *Greenwich* time being in the *Nautical Almanac*. This use of the moon preceded the invention of the chronometer, and perhaps the culminating point of pre-chronometer longitude determination was reached on Captain Cook's first voyage, when the longitude of Hawaii was determined from lunar observations (and observations of a transit of Venus) with an error of only a few miles. In his later voyages Cook took Harrison's newly invented chronometer with him. It may now be seen in the Maritime Museum at Greenwich. But the chronometer was never accurate enough to supersede the lunar observations on a long voyage out of touch with the land, and it is only the wireless time service which has rendered this use of the moon's movement obsolete.

Forty Years of Astronomy

By Sir Arthur Eddington, O.M.

(This is the second of a series of lectures organized by the History of Science Committee at Cambridge, and now published in "Discovery". Professor J. A. Ryle's account of the history of research on digestion appeared in the June number; next month we include Lord Rutherford's last public lecture.)

If we compare astronomy to-day with astronomy forty years ago, we notice a centrifugal tendency. Astronomical books in the 'nineties generally gave a full account of the sun, moon, planets, and comets, but could find little to tell us about the fixed stars. The centre of interest has now shifted from the solar system to the system of the stars, and beyond. We are likely to-day to hear more about galaxies than about planets.

This contrast may give a misleading idea of the pursuits of astronomy forty years ago. Actually the systematic observation of the stars was then absorbing the main energy of observatories as it had been doing, throughout the eighteenth and nineteenth centuries. In some of the work the stars were observed, not as celestial objects interesting in themselves, but as auxiliary to other researches; they were the reference marks, or graduations on the dial of the heavens, whose positions must be precisely calibrated to serve for measuring the movements of planets and comets. But besides routine observation of position, there were many kinds of investigations more directly concerned with the nature of the stars themselves. In 1900 the position was that, although actual results were still scanty and

uncertain, the labours of many decades were approaching fruition and a rapid advance was in prospect.*

For an understanding of the system of the stars the first essential is a general knowledge of stellar distances. The distances of two of the nearest stars, α Centauri and 61 Cygni, were determined in 1839; but there had not been very much advance in our knowledge by 1900. The number of well-determined parallaxes had increased to about 20; but these were not discriminated from a large number of inferior and quite misleading determinations. Even in 1910 the generally accepted catalogue of parallaxes listed 88 stars within 10 parsecs distance of the sun, of which 40 have since been rejected as beyond the limit. We knew very little about the distances of individual stars, and—much worse—we did not know how little we knew.

Soon after 1900 a great improvement was made by determining stellar parallaxes photographically instead of with a heliometer. The pioneers of the photographic method were Schlesinger at the Allegheny Observatory and Russell and Hinks at Cambridge. When the distance of a star has been found by parallax determination, its apparent brightness can be converted into absolute (intrinsic) brightness. The number of well-determined parallaxes now available is sufficient to give a good idea of the range of absolute brightness of the stars, and of the dependence of brightness on spectral type and other characteristics. The direct method of determining distances is of very limited application, since most of the stars are much too remote to give measurable parallax. But from knowledge of the nearer stars (within, say, a hundred light-years of the sun) derived in this way we have obtained a firm basis for developing and controlling a number of indirect methods of estimating the distance and absolute brightness of more remote stars—so that, by a series of steps, distances of objects up to 300 million light-years are now ascertainable.

Another type of measurement which developed very slowly was the determination of the radial velocities of stars. In principle the rate of approach or recession of a luminous body in the line of sight can be found by measuring the Doppler shift of its spectral lines. This was first applied to the stars by Huggins in 1868; but by 1900 we still did not know the radial velocity of any star. If any good determinations then existed, they were buried among the totally erroneous determinations. The practical development of the technique of this measurement is due to Campbell at the Lick Observatory. In 1913 trustworthy radial velocities of 1400 stars were available.

One kind of datum was fairly abundant in 1900, namely proper motion, i.e. the apparent angular motion of a star across the sky. These motions are larger than is often supposed; and with modern appliances it is the exception for a star to show no detectable motion in twenty years. The fastest motion is that of a faint star of magnitude 9·7 known as Munich 15040 (or less officially as Gilpin) which covers 10·3 seconds of arc per year; it would be just possible to detect its motion between two consecutive nights. Our knowledge of proper motions up to 1900 rested mainly on Bradley's observations of the positions of some 3000 bright stars around 1755, which were compared with the modern positions. Whenever a new catalogue of proper motions was produced, it seemed to be taken for granted that the one use for it was to determine the Solar Apex, i.e. the direction of the sun's motion relative to the system of the stars. You might think that this occupation would pall after a time; but happily each new determination disagreed with the older ones, and thus gave astronomers plenty to talk about.

In a general way the effect of the sun's motion amid the stars is quite conspicuous. If we plot the proper motions of stars in a small region of the sky we notice at once a preponderance in one direction; the stars

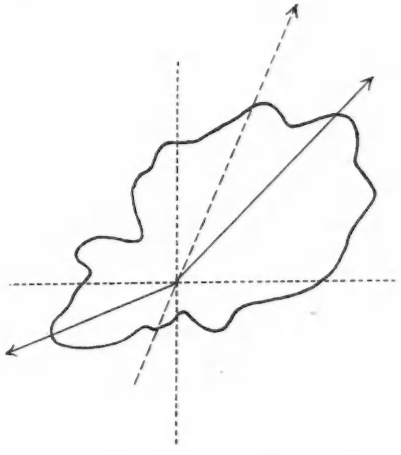
* An account of our knowledge at this time will be found in Newcomb, *The Stars. A Study of the Universe* (John Murray, 1902).

in the mean are moving in that direction relatively to the sun. This is expressed equivalently (but more modestly) by saying that the sun is moving in the opposite direction relatively to the stars. But though the general effect is plainly seen, an exact determination of the direction is difficult, since the apex is sensitive to small systematic errors in the system of the proper motions which we are still endeavouring to eliminate.

* * * *

Just at the time I entered astronomy (at Greenwich in 1906) a revolutionary discovery had been made. The greatest pioneer in the study of stellar statistics was Prof. J. C. Kapteyn of Groningen. There is now a long series of "Groningen Publications" relating to these problems. The most interesting of them all is No. 6. But it is no use going to a library to consult it; for the interesting thing about No. 6 is that it was never written. Nature took an unexpected turn, and would not fit into the scheme which No. 6 was promised to elaborate. No. 5 was entitled "The distribution of cosmic velocities: Part I, Theory"; it was a study of how the motions of stars pursuing their courses at random would turn out statistically when the solar motion and effects of varying distance were allowed for. Meanwhile the observed Auwers-Bradley proper motions were being prepared for comparison, so as to determine the numerical constants in the formulae. But the theory, though it represented the unquestioned views of the time, turned out to be so wide of the mark that not even the beginnings of a comparison were possible; and the application of the formulae had to be abandoned. This was Kapteyn's great discovery of the two star streams, announced at the British Association meeting in South Africa in 1905, which revealed for the first time a kind of organization in the system of the stars and started a new era in the study of the relationships of these widely separated individuals.

At first this discovery was received with much incredulity; but to any one who took the trouble to examine the proper motions for himself there could never be any doubt. For example, the diagram shows the statistics of distribution of the proper motions in a typical region of the sky; the radius from the dot to the curve in any direction is proportional to the number of stars whose motions are in that direction. You can see easily that there are *two* favoured directions of motion, indicated by the full arrows. The direction towards the solar antapex is shown by the broken arrow; although the stars in the mean move in this direction, they do not favour it individually. Evidently the double streaming cannot be accounted for by the parallactic effect of the sun's own motion; it is an intrinsic peculiarity in the distribution.



The phenomenon of two star streams has been abundantly confirmed; and it is found to prevail everywhere in the region over which our surveys of proper motions extend. Its real significance is still uncertain. It may be that in our neighbourhood two large clusters of stars have met by accident and are passing through one another. But in modern discussions star-streaming has to be considered in conjunction with another effect whose existence was demonstrated

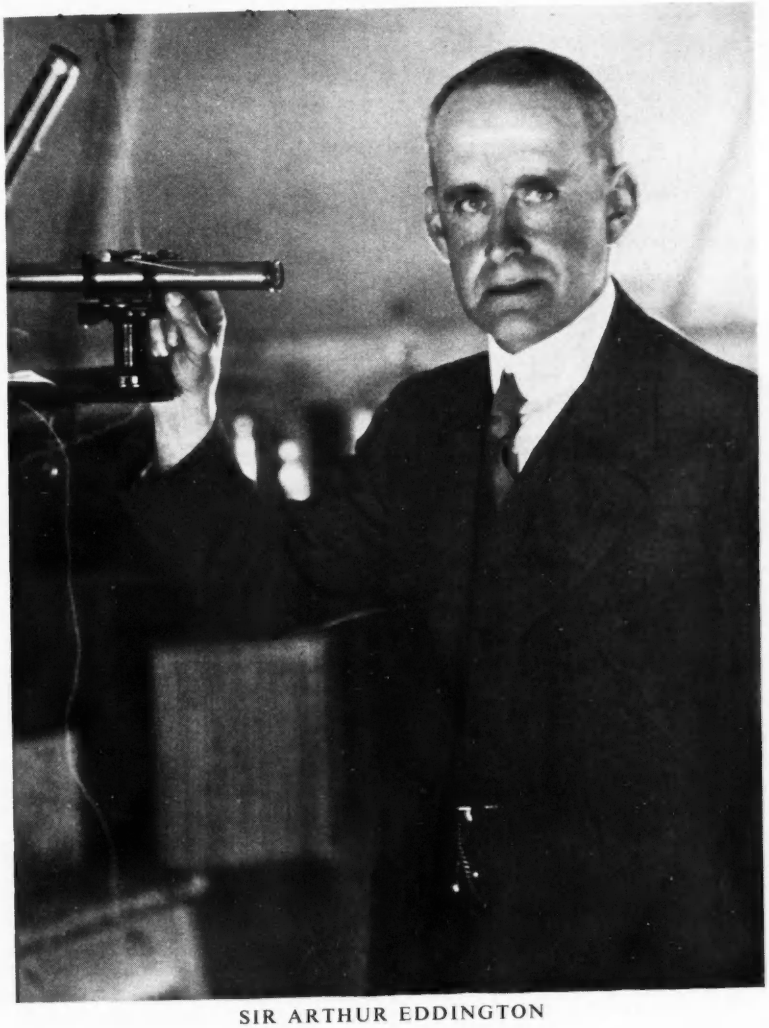
by Oort of Leiden about 1927. The whole galaxy is found to be rotating about a centre which lies 10,000 parsecs away in the direction of the constellation Sagittarius. This centre is fairly near to the vertex of the preferential motion; though according to the best determinations there is a difference of about 10°, which seems to be real. It suggests itself that Kapteyn's phenomenon is primarily a tendency for the stars to move radially (towards or away from the centre of the galaxy) rather than transversely, and that it is a general feature of the dynamics of the system.

* * * *

In accordance with the law of gravitation it is necessary that the rate of revolution of the galaxy should decrease outwards; just as in the solar system the outer planets revolve more slowly than the inner planets. Our survey of proper motions and radial velocities extends over what is after all only a small part of the whole galaxy; consequently in actual observation we are concerned only with the *differential* rotation in this small region. Since the outer part of a region travels more slowly than the part nearest the galactic centre, the region must become distorted. Considering a square with ourselves at the centre, the square will become sheered into a diamond. The stars seen in the two opposite directions corresponding to the lengthening diagonal will therefore (on the average) be moving away from us; those 90° away, corresponding to the contracting diagonal, will be coming towards us. The sheering effect, by which motions of approach and motions of recession follow at intervals of 90° of galactic longitude—or, as it is briefly described, the double-period term in the average radial velocity—is shown by all classes of distant stars. The results of the analysis, giving the direction of the centre and the magnitude of the differential rotation, are very accordant. The rotation indeed provides a means of estimating the average distances of various classes of stars; since the amplitude of the double-period term, which we obtain by analysis of the observed radial velocities, is proportional to the distance. This illustrates one of the indirect methods by which our knowledge of celestial distances has been extended beyond the limits within which parallax measurement is possible.

We are a long way from the centre of the stellar system—perhaps about half-way out towards its confines. In our neighbourhood the orbital speed is about 250 kilometres per second, and the time required for a complete revolution is of the order 250 million years. It is interesting to reflect that we have made five or six complete revolutions round the system within geological times. It is also possible to infer the mass of the system, which controls this orbital motion. It must be about 150,000,000,000 times that of the sun; so that presumably the system contains something like that number of stars. This is about ten times the number estimated by extrapolation of actual counts of stars; but it is not incredible, because vast numbers of stars may be hidden by the clouds of obscuring matter which are observed in various parts of the system and especially in directions towards the centre.

To return to the state of our knowledge in 1900—it was realized that the stars form a limited system strongly flattened in the galactic plane like a bun or lens. Newcomb, who was one of the leading authorities, concluded that the boundary of the stellar universe was nowhere distant more than 3000 light-years and might possibly be much less. The diameter now assigned to it is at least 20 times greater. But that is by no means the whole magnification that our conception has undergone. This huge system of a hundred thousand million stars is only the beginning; it is one island galaxy among many. Out beyond it there are other islands, recognized by us as spiral nebulae. From sample counts it is computed that 10,000,000 of these galaxies, coequal with our own island system, are detectable with our present telescopes; and doubtless there are far more outside their range. In forty years the "boundary" of the material universe has been pushed back from 3000



SIR ARTHUR EDDINGTON

light-years to beyond 500,000,000 light-years, which is the present limit of telescopic survey.

The status assigned to the spiral nebulae has undergone remarkable vicissitudes. The hypothesis that the nebulae are island galaxies was first put forward by Sir William Herschel, and for a time was widely accepted. When the spectroscope was introduced, Huggins found that many of the most conspicuous nebulae show the bright-line spectrum of a gas and are clearly not galaxies of stars. This discredited the island theory; and all the nebulae were brought inside our galactic system again. Later it became clear that the spiral or "white" nebulae are a different class of objects from the nebulae with gaseous spectra. About

1910 the island theory was revived as regards the spiral nebulae. It was advocated especially by Sir David Gill and an international group of astronomers associated with him; but Van Maanen, Jeans and others took the opposite view, and the question was strongly contested until 1924, when Hubble produced conclusive evidence that the spiral nebulae are extragalactic. The gaseous nebulae on the other hand are intragalactic.

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In some of the nearer spiral nebulae it is possible to recognize individual stars. Hubble found among them some Cepheid variables, and determined the periods of their light-variation. It is known from the study of Cepheid variables in our own galactic system that the period is a trustworthy indicator of the intrinsic brightness. Thus the absolute light-power of these stars could be assigned; and, by comparing it with their apparent brightness, the distances of the Cepheids, and of the nebulae containing them, were deduced. These distances showed them to be far outside our own galaxy.

The spiral nebulae are found to be moving away from us systematically with speeds approximately proportional to their distances. This indicates that the whole system of the galaxies is dispersing. At the present rate of expansion its dimensions will become doubled in 1500 million years—a period comparable with the age of the earth's crust. The rapidity of this change of the large-scale structure of the universe has profoundly modified our ideas of the time-scale of evolution in astronomy. Upper limits to the ages of the stars had been calculated on the extreme assumption that the whole of the energy of constitution of the matter contained in them is available for radiation; for example, the upper limit for the sun is five billion (5.10^{12}) years. Formerly it was widely believed that the actual ages correspond to these upper limits; but such values are now altogether incongruous. We cannot well assign to the stars a past duration more than a small multiple of the "time of relaxation" of the system of galaxies. For this and other reasons the age is now put not higher than 10^{10} years.

I dare not enter further into the discussion of this expansion of the universe, lest I be tempted to spend the rest of the lecture over it. But in view of the false impressions which exist, it is desirable to emphasize that it is a straightforward development of astrophysical research in which observation and theory very happily agree. The cause of the expansion is a force known as "cosmical repulsion" which is foretold by the equations of relativity theory. At very great distances Newtonian attraction is modified by this supplementary force, and in the system of the galaxies the resultant effect is a repulsion which scatters the galaxies apart. It would be contrary to the scientific spirit to represent this, or any other result described in this lecture, as safe from revision through the progress of knowledge. But it is not one of the more precarious advances; and there is no excuse for those who treat cosmogony as a field for unguided speculation of a type which would not be tolerated in any other branch of physical science. I think that a joint paper by Einstein and de Sitter a few years ago must be held partly responsible for this wave of speculation. It was a piece of mathematics, innocuous in itself, but put in such a way as to give the impression that these distinguished authorities had become sceptical about the cosmical constant. Einstein came to stay with me shortly afterwards, and I took him to task about it. He replied: "I did not think the paper very important myself, but de Sitter was keen on it." Just after Einstein had gone, de Sitter wrote to me announcing a visit. He added: "You will have seen the paper by Einstein and myself. I do not myself consider the result of much importance, but Einstein seemed to think that it was."

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To return to historical order, after the discovery of the star streams the next big sensation in stellar astronomy was the

Giant and Dwarf theory put forward by Hertzsprung and Russell, which came into prominence about 1913. In 1900 we were supposed to understand thoroughly the course of stellar evolution—the stars passed through the sequence of spectral types B, A, F, G, K, M in order, ending up as dark stars. The description of spectral types as "early" or "late", which is still commonly used by force of habit, is a reminder that at one time the above sequence was accepted with the utmost confidence. But whereas in most branches our knowledge has greatly advanced, our knowledge of stellar evolution seems to have diminished, until now it is represented approximately by the symbol O.

Apart from any evolutionary interpretation, the order B, A, F, G, K, M is that of diminishing temperature; the supposed passage of a star down this sequence therefore signified that its surface continually cooled. Hertzsprung and Russell discovered that each of the "later" types comprises two distinct classes of stars, widely different in absolute brightness and presumably also in physical condition. Within any one spectral type the surface luminosity must be approximately the same; thus the difference of brightness can only be attributed to difference of size. For example, the M stars are divided into a group of huge diffuse "giants" and a group of small concentrated "dwarfs"—with no intermediate M stars. As we go up the spectral sequence the giant and dwarf groups converge, and they coalesce in types A and B. To put the stars in order of increasing density, we must begin with the M giants, go up the sequence M, K, G, F along the giant branch to A or B, and then come down the dwarf branch to M again. Hertzsprung and Russell took this to be the order of evolution, the stars being supposed to begin as condensations in nebulae and to contract continually as they radiated away their heat.

It had been shown by Homer Lane in 1870 that when a gaseous star contracts its internal temperature must rise; this seemed to account for the ascending part of the evolutionary sequence which corresponds to diffuse giant stars. At the turning point in type B or A the density is beginning to approach that of water. It was naturally thought that the gas theory then ceased to apply; the second half of evolutionary sequence accordingly followed, in which the star descended the dwarf branch, cooling like a liquid or solid mass. We notice that the keystone of the Hertzsprung-Russell theory of evolution was that the change over from ascending to descending temperature occurs when the star becomes too concentrated to behave as a perfect gas. In view of the subsequent collapse of this theory we may call attention to a weak point in the argument. It confused the *internal* temperature (treated in Lane's theory) with the *surface* temperature (indicated by the spectral type); these do not necessarily increase and decrease together.

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The distinction of giants and dwarfs was a very important advance. In modern classification there is a slight modification. We recognize three groups: firstly, the Main Series, which is the old dwarf branch prolonged to include types A and B and a still hotter type O; secondly, the Giants, which are not very numerous in space, but owing to their great brilliance furnish the majority of the naked-eye stars; thirdly, the White Dwarfs, which fall on the other side of the main series, and have transcendently high density. But the evolutionary part of the theory has been abandoned altogether. It was my lot to bring about its fall in 1924 by showing that the dwarf stars, notwithstanding that their density is as high as that of terrestrial liquids and solids, are still in the condition of a perfect gas and have the compressibility of a gas. That contradicts what I have called above the keystone of the theory. Another upsetting result was that the absolute brightness of stars (other than white dwarfs) is determined almost wholly by their masses and is little affected

by their density; in particular, a dwarf has much smaller mass than a giant of the same type, so that we cannot take them as representing later and earlier stages of the same star—unless indeed a star loses mass as it grows older. For a time it seemed possible to save the Hertzsprung-Russell sequence of evolution by postulating that a star during its lifetime radiates away a large proportion of its mass. But this suggestion, which involves the hypothesis that electrons and protons can annihilate one another, has been undermined by the recent discoveries in atomic physics; and, moreover, the shortened time-scale already mentioned gives insufficient time for the required decrease of mass by radiation.

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Certain distinctive characteristics in the spectra of giant and dwarf stars have been found, so that they can now be distinguished easily without examining their absolute brightness. By an elaboration of the same principle Adams and Kohlschütter developed in 1914–16 a spectroscopic method of determining absolute brightness. As already stated the stars can be arranged in sequence in order of surface temperature, certain features of their spectra being used as criteria. Other less obvious features give a classification which runs athwart the temperature classification. It is found that this transverse classification is governed by the absolute brightness. This gives an empirical method of determining the absolute brightness, stars whose absolute brightness is already known being used to calibrate the scale. By comparison with the apparent brightness we can deduce the distance or parallax. The results of this method are therefore called "spectroscopic parallaxes".

In 1920 the angular diameter of a star was measured for the first time by Pease and Anderson with an interferometer constructed by Michelson. The stars are so distant that no disc can be seen even in the largest telescope; the image is always indistinguishable from that of a point. Actually it is not difficult to compute their angular diameters from their apparent brightness and the approximately known effective temperatures of the different spectral types; but a check on the theory is always desirable, particularly as in this case it led to what appeared to be outrageously improbable results for the comparison of Sirius and other white dwarfs. Probably no star has a disc greater than $\frac{1}{20}$th of a second of arc; the largest should be those of the first magnitude stars of type M, namely Betelgeuse and Antares. Using apertures separable up to 20 feet, after the pattern of a range-finder, Pease and Anderson obtained diffraction effects for Betelgeuse from which a diameter of 0″·045 was deduced. This gives a linear diameter of about 300 million miles; that is to say, Betelgeuse is large enough to contain the orbit of Mars. To extend the method to somewhat smaller stars a 50-foot interferometer was built; but it was not brought into successful use until 1936.

I became interested in the theory of the interior of stars in 1915. The hypothesis that the short-period variable stars of a particular class known as Cepheids, first proposed by Plummer, had recently received strong support from the researches of Shapley; and I wanted to investigate the thermodynamic problems connected with the maintenance of a pulsation. But it was not until some years later that I was in a position to begin the investigation of pulsations; for it soon became clear that the existing theory of a static star needed to be modernized to correspond with advances which had been made in the physics of radiation.

You must understand that by "modernized" I do not mean that I intended anything so revolutionary as the introduction of quantum theory. I suppose I believed in quantum theory after a fashion—in so far as anyone could believe the tissue of inconsistencies that it then was. But it was not the sort of thing for a matter-of-fact astronomer to have dealings with. You may

find it difficult to recall the outlook of those benighted days. Let us go back to 1912. At that time quantum theory was a German invention which had scarcely penetrated to England at all. There were rumours that Jeans had gone to a Conference on the continent and been converted; Lindemann, I believe, was expert on it; I cannot think of anyone else. Soon afterwards Bohr's theory of the atom appeared, and quantum theory reached the stage at which one says: "There seems to be something in it, and I really must read it up when I get time." By 1915 everyone was reading Jeans's "Report on Quantum Theory", published by the Physical Society; and upholders of the "pint-pot" type of explanation were being driven into the last ditch. So the theory was very much under discussion. But as you must have realized, I am always very conservative in my outlook and do not accept anything until it has become quite obvious that it is true; and I did not want the work I was doing on the structure of the stars to be mixed up with half-baked theories.

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However, a point soon arose where quantum theory could not be evaded. Following all earlier writers I had taken the ultimate independent particles in stellar material to be atoms, and had adopted appropriate masses for them. Newall first suggested to me that it was more likely that there would be complete ionization, setting free all the satellite electrons; if so the average mass per particle would be much lower. The quantum experts Jeans and Lindemann were of the same opinion. It seems to have been a matter of opinion only, for there was no recognized quantum theory of ionization at that time. I found the suggestion attractive, because it made my numerical results nearly independent of the unknown chemical composition of the stars, the average molecular weight of fully ionized matter being nearly the same for all elements except hydrogen. Calculations were therefore made both on the assumption of high ionization and of low ionization, it being left to observational comparison, or to the future development of theory, to decide between them.

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The present ionization formula, as given by quantum theory, was first applied to the stars by Eggert in 1919; and it confirmed the hypothesis of high ionization which was already provisionally assumed. In 1921 Saha studied in the same way the state of ionization of the outer layers of a star, and started the modern theory of the interpretation of stellar spectra. This has opened out a very wide field of practical and theoretical investigation. It is in fact the parent of most of the problems of modern astrophysics.

One outcome of the theory of the interior of a star was the realization that matter in dwarf stars, though comparable in density with iron or water, still behaves as a perfect gas and is therefore far from the limit of compressibility. There is no obstacle to densities hundreds or thousands of times greater. It suggested itself that this was the explanation of a difficulty presented by the white dwarf stars. The companion of Sirius, for example, gives only $\frac{1}{360}$th of the light of the sun, although judging by the spectral type its surface should radiate more strongly. The star must therefore be much smaller than the sun, the computed diameter being no more than 25,000 miles. The resulting density, about 60,000 times the density of water, had appeared to indicate a fallacy in the deduction, and had cast suspicion on the reliability of spectral type as a guide to temperature. But on the new theory the high density was not incredible, and the calculation might be accepted literally.

To decide the question Adams investigated the Einstein shift of the spectral lines in the companion of Sirius. The shift, which is proportional to the gravitational potential at the surface of the star and therefore varies as mass divided by radius, would be

very large if the small radius were correct. In 1925 the large shift was observed, and the high density was confirmed. Even this is not the highest stellar density; although only rough estimates can be given for the other known white dwarfs, it appears that in some of them the density must be at least 100 tons to the cubic inch.

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Up to 1924 no one seems to have given serious thought to the possibility of superdense matter. By a strange coincidence, just when astronomers were discovering its existence in the white dwarf stars, the thoughts of pure physicists were independently turned in the same direction. Wave-mechanics was found to introduce deviations from the classical statistical theory of particles, which in general could only be appreciable at extremely high density. To those seeking an application of the new theories the white dwarfs were a godsend. The new (Fermi-Dirac) statistics were first applied to them by R. H. Fowler, who thereby cleared up a serious difficulty as to the energy-content of the white dwarfs.

In the later part of the period here surveyed the greatest advance perhaps has been in the study of gaseous nebulae. These are extremely rarefied objects with density generally of the order 10^{-20} gm. per cu. cm. Some of them (planetary nebulae) surround one star only; others (irregular nebulae) are much more extensive and enclose many stars. In all cases one or more stars of very high temperature must be enclosed, because the nebular light is due to stimulation by extreme ultra-violet radiation from the stars. The light is not a simple reflection but a fluorescence effect.

For many years the principal puzzle was the nature of the bright spectral lines responsible for the light of the nebulae, since the most conspicuous lines could not be traced to any known element. A new era began in 1927 when Bowen found that a number of the unknown lines were "forbidden" lines of ionized oxygen and nitrogen. In fact the material which had puzzled us was just air. These forbidden lines have not been observed in the laboratory; but their theoretical wave-lengths can be calculated from those of the ordinary lines in the spectrum of the same element and identified with the observed nebular wave-lengths. They represent downward transitions from a metastable state, that is to say a state in which the atom will usually remain a long time (from a second to several hours) before it falls to a lower state with emission of radiation. Consequently to emit forbidden lines the atom needs to be left undisturbed for long periods—a condition impossible to secure in the laboratory but satisfied in the nebulae, where the sparsely strewn atoms and electrons travel for hours without meeting, and the radiation is so dilute that encounters with photons are equally rare.

Following up this result Zanstia produced a very fascinating theory which traces in detail the transformations of radiation in the nebula, enables the effective temperature of the stimulating star to be calculated, and accounts for the principal facts observed. Unfortunately it is too lengthy and technical to be described here.

I need scarcely say that in this brief survey of forty years' progress in astronomy much must be omitted; I must not, however, neglect the solar system entirely. Its recognized membership has increased by four more satellites of Jupiter, one of Saturn (discovered in 1898), 940 minor planets (bringing the total to 1380), and one major planet Pluto. The trans-Neptunian planet Pluto was discovered by Jombaugh in 1930. It has a period of 248 years as compared with Neptune's 165 years, and a mean distance from the sun of 3600 million miles compared with Neptune's 2800 million miles; but its orbit is so eccentric that at perihelion it comes slightly nearer to the sun than Neptune. Estimates of its diameter and mass are still only hypothetical; but it seems certainly smaller than the earth, and may perhaps be about the size of Mercury. It was found in the course of a search made at the Lowell Observatory

for a trans-Neptunian planet predicted by the late Prof. Lowell from a study of the perturbations of Uranus. It turned up close to the predicted spot. But it has since been shown that it could not have been responsible for the perturbations, and the agreement must be set down as pure coincidence.

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Perhaps the most generally interesting advance in this part of astronomy has been the spectroscopic study of the atmospheres of planets. Our familiar atmosphere of oxygen and nitrogen, with a certain amount of water-vapour, is not by any means a standard equipment. The atmosphere of Mars, though rather scanty, is not dissimilar to that of the earth; but all the other planets show significant differences. Mercury (like the moon) shows no trace of an atmosphere. Venus is covered by thick cloud and only the upper atmosphere above the cloud can be examined; its spectrum shows carbon dioxide, but no oxygen. It is thought that this signifies that there is no vegetation of the terrestrial type on Venus; since on the earth vegetation performs the function of absorbing carbon dioxide from the atmosphere and returning the oxygen. This is in keeping with another line of speculation which had suggested that the surface of Venus is entirely covered by ocean. On Jupiter and Saturn we find atmospheres of an entirely different constitution, namely a mixture of methane and ammonia—which seems an extraordinarily unpleasant combination! The proportion of ammonia is less on Saturn than on Jupiter; and on the still more remote planets Uranus and Neptune only methane has been detected. This progressive decrease of ammonia may be attributed to the increasing cold which removes it from the atmosphere by liquefaction.

The presence of hydrides (CH_4 and NH_3) in the atmospheres of the four large planets suggest an excess of hydrogen in their composition. In the last ten years we have come to realize that hydrogen is an extremely abundant element. Studies of the interior of stars, of the surface layers of stars, of the gaseous nebulae, have all independently led to this conclusion; and one of the leading factors in the progress of the last ten years has been the revision of older views which had not appreciated the important part played by this element. It can generally be taken that hydrogen is nearly as abundant by mass as all the other elements put together, and far more abundant if we reckon by number of atoms. We therefore assume that when the planets were formed from the sun, the material originally contained abundant hydrogen. That it is not so important a constituent of the earth is explained by the theory of escape; the earth's gravitational field was not strong enough to prevent the light and fast-moving atoms of hydrogen from leaking away. But the massive outer planets have a stronger field and could retain their hydrogen. This gives a satisfactory explanation of the different constitution of their atmospheres; and a detailed chemical study of the problems raised throws much light on the physical condition of these planets. I will only add here that the conditions are intensely cold, and all the water must lie ice-bound on the planet's surface—concealed from us and from the sun's rays by the deep opaque atmosphere.

I will devote the few minutes which remain to the most exciting event I recall in my own connection with astronomy, namely the verification of Einstein's prediction of the deflection of light at the eclipse of 1919. The circumstances were unusual. Plans were begun in 1918 during the War, and it was doubtful until the eleventh hour whether there would be any possibility of the expeditions starting. But it was very important not to miss the 1919 eclipse, because it was in an exceptionally good star-field; none of the subsequent expeditions have had this advantage. Two expeditions were organized at Greenwich by Sir Frank Dyson, the late Astronomer Royal, the one going to Sobral in Brazil and the other to the isle of Principe in West Africa. It was impossible to get any work done by instru-

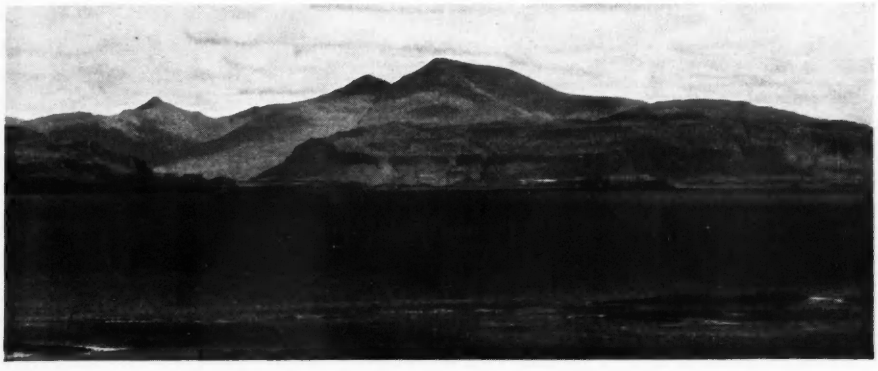
ment-makers until after the armistice; and, as the expeditions had to sail in February, there was a tremendous rush of preparation. The Brazil party had perfect weather for the eclipse; through incidental circumstances, their observations could not be reduced until some months later, but in the end they provided the most conclusive confirmation. I was at Principe. There the eclipse day came with rain and cloud-covered sky, which almost took away all hope. Near totality the sun began to show dimly; and we carried through the programme, hoping that the conditions might not be so bad as they seemed. The cloud must have thinned before the end of totality, because amid many failures we obtained two plates showing the desired star-images. These were compared with plates already taken of the same star-field at a time when the sun was elsewhere, so that the difference indicated the apparent displacement of the stars due to the bending of the light-rays in passing near the sun.

As the problem then presented itself to us, there were three possibilities. There might be no deflection at all; that is to say, light might not be subject to gravitation. There might be a "half-deflection", signifying that light was subject to gravitation, as Newton had suggested, and obeyed the simple Newtonian law. Or there might be a "full deflection", confirming Einstein's instead of Newton's law. I remember Dyson explaining all this to my companion Cottingham, who gathered the main idea that the bigger the result, the more exciting it would be. "What will it mean if we get double the deflection?" "Then", said Dyson, "Eddington will go mad, and you will have to come home alone."

Arrangements had been made to measure the plates on the spot, not entirely from impatience, but as a precaution against mishap on the way home; so one of the successful plates was examined immediately. The quantity to be looked for was large as astronomical measures go, so that one plate would virtually decide the question, though, of course, confirmation from others would be sought. Three days after the eclipse, as the last lines of the calculation were reached, I knew that Einstein's theory had stood the test and the new outlook of scientific thought must prevail. Cottingham did not have to go home alone.

I have told you, as best I can, something of what we have learnt in the last forty years. I will end by expressing a hope—not unmingled with doubt—that not too much of what I have been saying will be upset in the next forty years.

(Dr Darling's work as a biologist is largely done in the field, by observation of animals in natural conditions. He has done a great deal of this work in the Highlands of Scotland or in the islands off the west coast. In this article he describes and illustrates the kind of country and weather in which it is his lot, or luck, to work.)



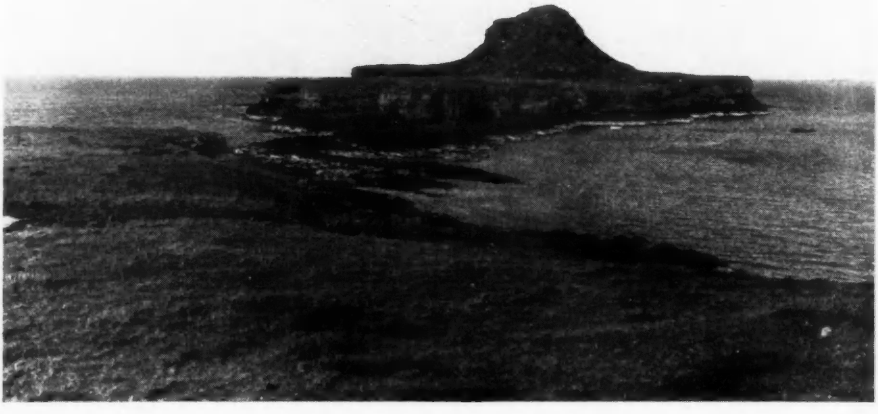
The Treshnish Isles

By F. Fraser Darling

MY first view of these little dots in the sea was from the summit of Ben More Mull on a spring evening years ago. The broad bands of Loch na Keal and Loch Scridain were below me; Ulva and her little islands were nearer the sunset, and beyond, over a few more miles of sea, was the bold outline of the Dutchman's Cap, which is like a sentinel of the Treshnish Isles meeting the sou'westers from the open Atlantic. The other islands strung away northwards until they almost reached the Mull shore. Little did I know then that the time would come when I should stay on the islands for several months, and have this very summit I was now on as the most prominent landmark.

Ben More Mull is 3170 ft. in height, and because of its isolation it stands out as a very high hill, visible from many places as far apart as Ireland, the Outer Hebrides and Ben Nevis. It is also a hill of beautiful lines, best seen from the west, either in the early morning when the sun is rising behind it, or late in the evening (see cover picture) when the low sun from the west gives it a sharp outline and discloses the physical details of the hill.

This part of the West Highlands is not so rugged as farther north and, because we have lived on Eilean a' Chleirich and had the view of that welter of sgurrs from Sutherland to Torridon, it was natural we should compare the two coastlines seen from the islands. On the Treshnish we could see from Ardnamurchan southwards to the Ross of Mull and Iona, over which we could see the Paps of Jura. This



Bac Mor, or the Dutchman's Cap

skyline culminated in the peak of Ben More Mull to achieve a restrained and perfect climax. We thought the colours softer here compared with the brilliant, clear light farther north, and we loved both views so much that we decided it would be invidious to express greater liking for the one than the other. So much depended on the coincidence of personal mood and the conditions of light and weather in which each coast and skyline was seen.

The lighthouses also made us think of the two islands at the same time. When I go to the sun recorder on a little hill on Eilean a' Chleirich late in the evening, I see the blinks from Rudh' Rhe, Ross-shire, Point of Stoer, Sutherland, and Tiumpan Head, Lewis. I know their individual patterns of flashes and often wait to see them all go through a round or two. And on fine November evenings on the Treshnish we would go to the Cruachan of Lunga and watch the lights. There was Ardnamurchan to the north-east, two flashes every twenty seconds; Dhu Artach to the south, two flashes every thirty seconds; and Skerryvore, south-westwards, one flash every twenty seconds.

I remember such an evening after a terrible period of storm. The wind blew from the south-east at hurricane force after two days of it as a gale. What a miserable wind it is, for it brings up a grey murk that takes the colour out of land and sea and sky, and as it is usually a dry wind our nostrils catch none of the beautiful scents of sea and earth. These times of south-east wind were not enjoyable; they

Cairn a' Burg Mor, showing the rock arch. This island was once fortified strongly

had to be lived through and were a test of nerves and patience. On this night the rain came also, and when it stopped at three o'clock in the morning I knew it would be difficult to get the guy ropes tight as they dried. Trouble began at four o'clock when the eave ripped from the windward side of the tent. In half an hour another stretch of canvas had gone and the increased wind resistance the tent now offered was causing us concern.

This happened to be also the time of the high spring tide, and as our boat was drawn up on the east side I felt I should go to see if it was secure, for with such a gale coming on that shore there was no knowing how far up the sea would come. I went down the path through the cliff, finding it hard to keep my feet, and a thrush fluttered from the ground and hit my electric lantern. I picked it up and placed it in a safe place under a rock, but the poor creature had not wits enough to stay there. It flew up into the night and I saw in the light of my lamp that the wind carried it towards the north sound where the sea roared. I wished then I had kept the thrush in my pocket until morning. The boat was all right, though the tide was higher than I had ever seen it on Lunga before.

When I got back to the tent the whole of the eave had ripped off, and the side had come in and was cracking about us like a cannon. We made room in the store tent, moved essentials from the stricken one, lifted the pole, let it down and put boulders on it before it was ripped to ribbons. This tent had ridden out

many a gale in two years, and we felt it keenly that so good a home should be beaten now.

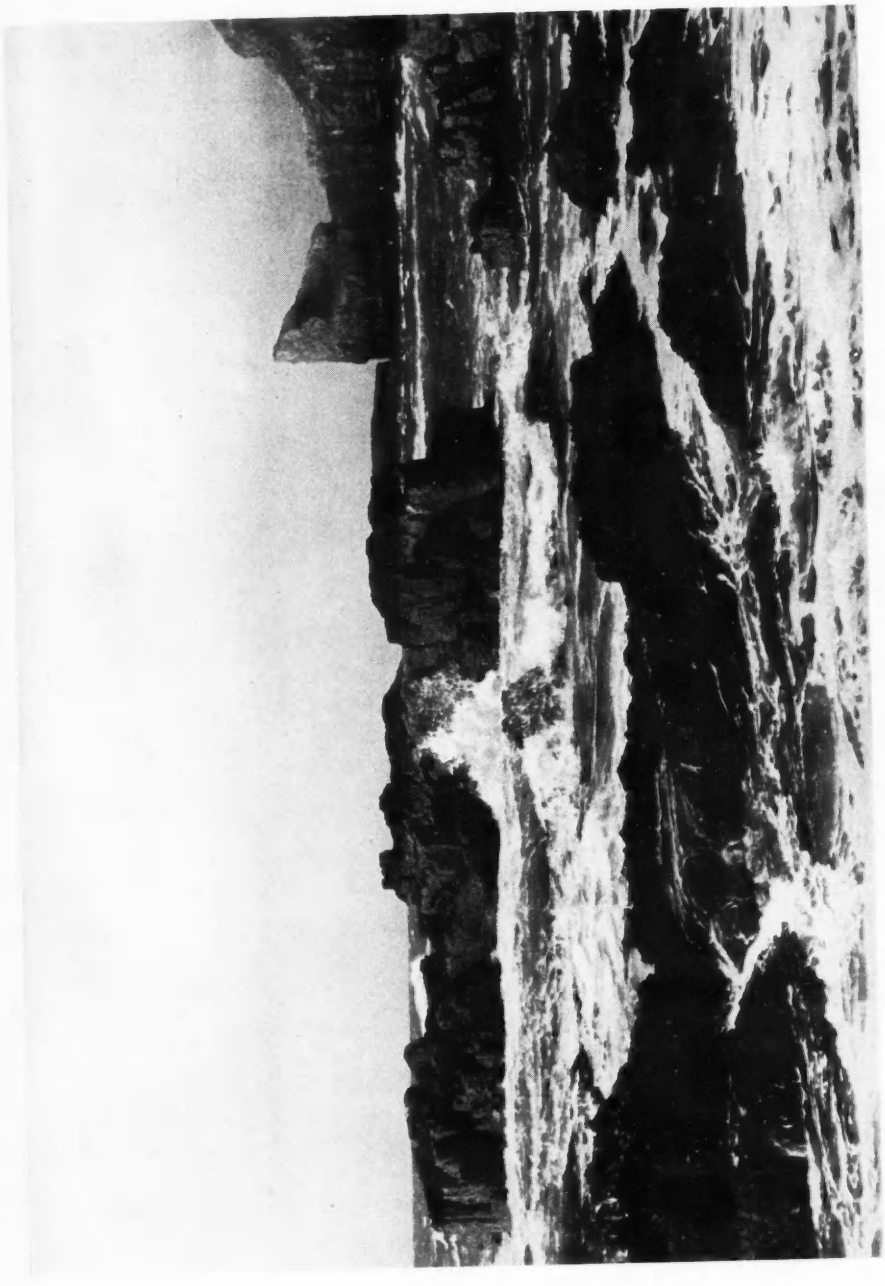
The sunrise behind Ben More that morning was the most wonderful I have ever seen, and the most dangerous. The gale was still blowing as hard as ever, and when I looked at this riot of green and gold, banks of cold steel grey and patches of vivid cobalt blue—a colour I had never seen before in the sky—I knew we could expect no cessation yet. We endured another day before the blessed calm fell.

The early Celtic nature poetry contains innumerable allusions to the wind, for it is the scourge of the western seaboard, and sayings from that almost lost store remain to-day among the island folk. The day which follows these dreadful storms is often of poignant beauty and serenity, and is called in Gaeldom "peace in the mouth of the beast".

All the cloud blew away that day and the moon rose in a fine clear sky. The sea was a sheet of silver, the grass a fairy carpet and the dull grey rocks of the island were silver also in this lovely light. To-night the sea only murmured, the wild geese called as they settled to graze on Creag a' Chaisteal and Sgurr an Erionnach, and the cheerful note of the snipe came welcome to us as the birds came down near the tent.

We were on the Treshnish when the barnacle geese came south for the winter, on 21 October. The gaggling cry of geese is very exciting to the human mind, and we rushed out of the tent to catch sight of them that early morning. More and more came during the day and night in gaggles and skeins of three up to seventeen birds, until several hundreds had passed us. A sequence of behaviour then began which we had not seen before. The birds gradually collected into a large flock and, instead of beginning to feed, as it would be imagined they would after the long journey from Greenland, they packed close on certain skerries north-east of Lunga, particularly Sgurr an Erionnach and Sgurr na h' Iolaire. The latter skerry is bare of vegetation, and on the other the geese were on bare rock. Excitement, with occasional concerted flights, prevailed for a week and then the birds settled to feeding on Cairn a' Burg Mor and the Dutchman. Lunga, for some obscure reason, is not frequented by the geese nearly so much as the other islands. This fact was noted by Harvie Brown fifty years ago and it holds good to-day.

A playful aeroplane gave us a superb spectacle one day in November, and for the data it gave me I forgave the naughty pilot for dipping over the Dutchman and putting up the flock of about a thousand barnacle geese. There may have been more birds than that, but as Kenneth McDougall, my wife and I were all together on the south end of Lunga that afternoon and each reckoned a thousand as a conservative estimate, that number can stand. We could hear the commotion of voices over the three miles of sea. The birds rose in a cloud into the gold of the dying sun, and we could see through our binoculars that the string formation of what I believe are the separate families, was kept within that great concourse. After a few minutes of flying round the Dutchman high in the air, they began to come our way. First



The West Coast of Lunga of the Treshnish Isles, showing the Sanctuary Rock

a string of a hundred; half a minute's lull; then three geese; then the main flock passed us on its way north-east to Cairn a' Burg Mor. It was during the course of this pageant we made the estimate of numbers in full knowledge that flocks of birds tend to appear composed of larger numbers than they really are.

The birds settled on the flat top of Cairn a' Burg Mor, the island of the Treshnish which was fortified by a Maclean chieftain and made as impregnable as Dumbarton Rock. Those old buttresses are now falling, but they still show the cleverness and ability that went into their construction. The manuscript library of Iona is supposed to be buried on Cairn a' Burg Mor, and it may be hoped that in the future the ancient buildings will be protected by H.M. Office of Works and be the subject of skilled and sympathetic excavation. They are unique in the West.

Moving sheep from Cairn a' Burg Mor

Notes of the Month

Further Evidences of the Antiquity of Man in America

A FURTHER stage has been reached in the discussion of the date of appearance of early man in America. The Carnegie Institution of Washington, D.C., reports the discovery of stone implements in Lake County, California, which are shown definitely, on stratigraphical evidence, to be earlier than the Folsom industry.

The Folsom stone industry, of which the most characteristic form is a stone point (arrow or javelin head), of a peculiar and distinctive shape, involving a highly skilled technique, was first definitely recognized a little over ten years ago as the culture of a stone-age hunting people, occurring over a wide area in the south-western United States, in association with an extinct mammalian fauna. It takes its name from one of the sites of the culture at Folsom in New Mexico.

Although the association of the Folsom industry with an extinct fauna, such as, for example, an extinct species of bison, does not give in America the same assurance of a high antiquity as it would in Europe, owing to local conditions, yet this industry has been accepted hitherto as the earliest evidence for the antiquity of man on the American continent, which rested on anything like an assured basis, and as justifying the attribution of an age to man there of anything from seven to twelve thousand years.

The new discovery in California was made by a joint expedition of the Carnegie Institution and the South-West Museum of Los Angeles under the leadership of Mr M. R. Harrington. Excavations were carried out on the sides of a brackish pond, where stone implements of Folsom type had already been found. In the upper layers of soil, which had been disturbed by the plough, the expedition found Folsom implements in association with others of a quite distinct type. Implements similar to the latter have been found recently at Mohave Lake and one other site, and hence are known as the Mohave type; but their relation to the Folsom industry was obscure. Further excavation on the Lake County site revealed the existence of a camp deposit, in which implements of the Mohave type appear at a definitely lower level, antedating the Folsom implements.

At about the same level a new type of spear head was found which has been named the Borax Lake type.

This, however, is not the whole story. Excavations were continued, and at a still lower level older and cruder implements have been discovered. They are mainly large scrapers and hand-axes. They belonged to a people who as yet are "an entirely unknown quantity in American archaeology".

On the assumption that the stratigraphical evidence will withstand future tests and criticism, it is evident that the antiquity of man in America must be moved back at least two stages earlier than Folsom man, while those American archaeologists who have been much criticized for their acceptance of a typological sequence, analogous to that in the stone age of Europe, find some measure of justification.

It is calculated that, on the basis of the new finds, an antiquity may be allotted to early man in America of some fifteen thousand years, in place of the seven to twelve thousand years variously estimated for Folsom man.

E. N. Fallaize.

Flowers Pollinated by Birds and Mammals

Everybody knows that insects repay flowers for the nectar and honey they obtain by transferring pollen to the stigmas and so fertilizing them, and as insects only visit flowers during the brief imago stage the short flowering-season of our temperate zone is enough to satisfy them. This, however, would not be long enough for animals. Tropical vegetation, which blooms the whole year round, might also supply birds and mammals with flower food. The fact that small tropical birds, such as the honey eaters or sun birds, also help in pollinating flowers, has been known for a long time, but according to Prof. Otto Porsch of Vienna, a specialist in this field, comparatively little investigation has been devoted so far to the inter-relationship between flowers and large birds or small mammals. The following statements are taken from his papers.

Various types of mammals—marsupials, rodents, small beasts of prey, among them day and night animals, half-apes and man-apes—relish the nectar. It is strange that only the oldest and lowest types of non-flying mammals, for example marsupials, are known to act as fertilizers, while among animals of a higher level a great many seem only to destroy the flowers on which they feed without being of service to them.

The most perfect adaptation to flower food is found in bats and Australian climbing marsupials (Phalangeridae), in the Old World Macroglossinae (flying fox), and in the American Glossophagidae (long-tongued vampires). Their characteristics are chiefly in the structure of a very long tongue, of the oesophagus, and mucous membranes; and in the reduction of the size of teeth and digestive system. The honey-mouse, for example (*Tarsipes spenceri* Gray), which lives in the south of Western Australia, has an exceedingly long wormlike tongue and a pointed muzzle. Though it is a marsupial it looks like a big mouse; its cheek teeth are minute and rudimentary, and it has no caecum. The smallest mammal of all, *Acrobates pygmaeus*, is also a marsupial. It measures 5 or 6 in. in length including the tail,

and about 3 in. without the tail. The smallest mammal and the smallest bird, the honey-sucker, live on flower food. According to Prof. Porsch, some of the flowers that the honey-sucker visits are so constructed that the bird can only take up and transmit the pollen if it leaves the flower in the same direction in which it entered. This means that it must fly backwards, a fact Porsch was actually able to observe in Costa Rica.

* * * * *

An example of flowers exploited by non-flying mammals is the genus *Bombax* about fifty species of which are to be found in tropical zones. Their nectar can easily be drunk by mammals living in trees, because it is secreted in large quantities by their gigantic flowers. In *Bombax malabaricum* the stigma is about 3 in. above the nectar glands. Therefore it is equally fitted for fecundation by large birds, even if they are not very well organized for the purpose, such as *Pastor roseus* or some crow species.

In the case of *Erythrina indica* the axis of the inflorescence is solid enough to bear the weight of squirrels or heavy birds without being bent.

Several flowers—for example, various species of *Kigelia*, *Markhamia*, *Oroxylum*, *Crescentia* and *Illipe*—are indubitable "bat-flowers", and it is characteristic of them that the climax of their floral life is reached during the night hours, when they also secrete large quantities of nectar, develop a strange scent, and their flowers, very large, are provided with a wide entrance which is easily accessible.

Squirrels, too, have been observed skilfully balancing on hanging inflorescences of *Kigelia aethiopica*, pushing their little heads into the flowers and then springing away. After being allowed to repeat this manœuvre two or three times they were killed, and their digestive organs were found to be crammed with flower material.

Although in typical bird flowers, such as compositae, the flowers are massed into heads filling the entire placenta, Porsch observed a *Dryandra nivea* in the Schönbrunn garden in Vienna in which the central part round the axis was entirely free from blossoms. This flower also exhaled a scent which seemed to him at first like that of boiling milk, but was actually more like that of sour milk, yet, when he came nearer, had an aromatic by-smell like caraway brandy. Such strong scents seem to be characteristic of mammal flowers. In 1893 the Viennese botanist Kerner von Marilaun maintained that a *Dryandra* species was visited by kangaroos, but this observation was deemed fantastic, and disbelieved by everybody, but Porsch now seems inclined to believe it. Some flowers are certainly big enough to be exploited by dwarf kangaroos as well as climbing marsupials.

Again, a cacadoo (*Zandra funers* Math), 2 ft. in length, was observed drinking nectar. In Palermo rats have been seen drinking this beverage from an *Agave* and other plants, and the flowers were not destroyed. Even a small beast of prey, the Indian Charsa marten, does not despise this divine and innocent drink.

According to Porsch it was thirst that first attracted animals to flowers. They drink the nectar, they drink the juicy fruits and tissue saps, spitting out the fibres, and they also drink the water which tropical plants often keep stored in thick-walled cells in leaves and flowers. Flying foxes are known to relish palm wine, drinking until they fall to the ground intoxicated.

[*From G. Rabel, Vienna.*]

Scientific Films

A scientific Film Group of the Association of Scientific Workers was formed over a year ago to encourage the growth of good instructional and documentary films, dealing both with pure science and, perhaps even more important, with science as a social force. It sought to supply a long-felt want by giving the public opportunities to see and estimate the impact of science on modern life, and was intended to assist in fostering a scientific spirit applied to everyday problems.

The Group has accordingly given shows of approved scientific films in London, Cambridge, Oxford, and elsewhere, and these have demonstrated that there is a considerable public eager to see such films. To enable the group to continue on a more ample scale in London, however, while complying with L.C.C. regulations, it has now become necessary to consider forming a Scientific Film Society. Such a Society would be open to all interested persons and would give at least four film shows a year in a London cinema on Sunday afternoons. There would be two rates of membership subscription, 10*s.* and 15*s.*, the higher rate entitling subscribers to the better seats. It would not be possible to sell tickets for such shows to the general public, but a limited number of guest tickets would be available to members. Any profits arising from the Society's work would be devoted exclusively to non-commercial purposes such as the making and adapting of scientific films.

We understand that the Committee would be glad to hear from anyone who, without in any way committing himself, would consider joining such a Society, and interested readers are asked to apply direct to the Secretary, The Scientific Film Group, Kelvin House, 28 Hogarth Road, South Kensington, London, S.W. 5.

* * * *

Dr Fraser Darling's photographs of birds in flight in our June issue have received wide commendation. May we suggest that readers who intend to bind their *Discovery* should keep the cover of this issue and instruct their binders to trim, mount, and bind-in the picture of the "herring gull in downward swoop" which made the cover so popular. We regret that one correction is necessary. The picture of the first plumage of the two young gulls on p. 110 should have been entitled "Young black-backed gulls" etc. Will readers who care for accuracy make this correction?

How Engineers overcame Nature, and carried out the Hydro-Electric Power Scheme

Harnessing the Victoria Falls

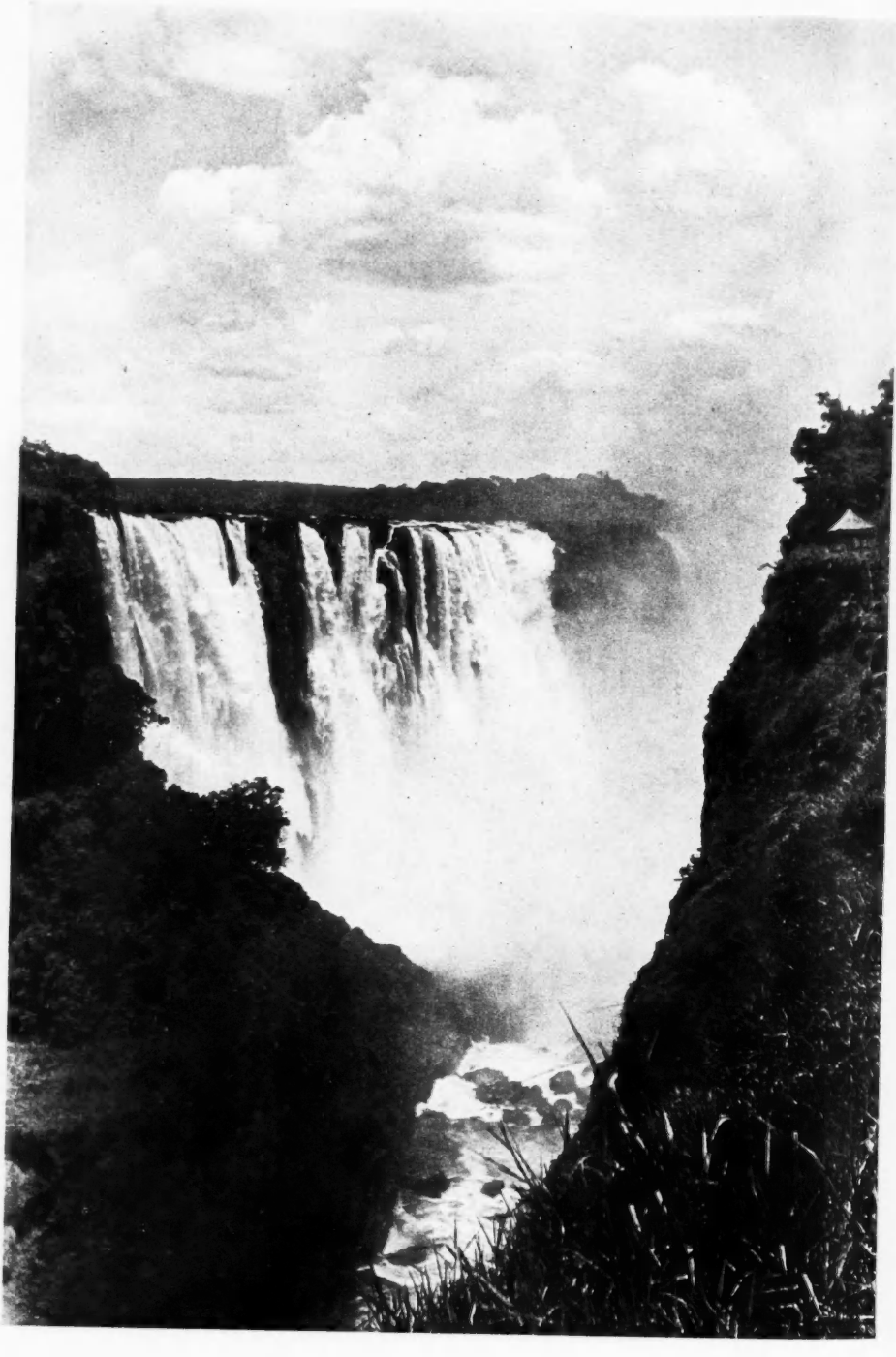
By Denys Parsons

ON 16 March the Governor of Northern Rhodesia, Major Sir Hubert Young, opened the new Victoria Falls hydro-electric power station. The immediate object of the scheme is to supply power to the neighbouring town of Livingstone and to the Falls Hotel on the Southern Rhodesian side of the Zambesi.

The construction of the plant was begun in June 1936, and it will very soon be in full service. At the request of the Government great care was taken to avoid spoiling the beauty of the Falls. The water inlet is some distance above the Falls

and an underground pipe-line leads to the top of a gorge some distance below them. An overhead power cable was necessary in one place, but it was put as far from the Falls as possible and it will not be seen by tourists. Even in the dry season the quantity of water taken by the Power Station is negligible in comparison with the total flow over the Falls.

The Power Station houses two reaction turbo-generators each giving 1000 kilowatts. The head of water is almost constant throughout the year at 350 ft., and at full load 2500 cubic ft. of water per minute are taken. The scheme has been carried out by the Victoria Falls and Transvaal Power Co., the turbines being supplied by the English Electric Co., and the pipe-line by the South Durham Iron and Steel Co. There is a 60 ft. deep settling tank at the top of the gorge, which may be made into a public swimming bath.



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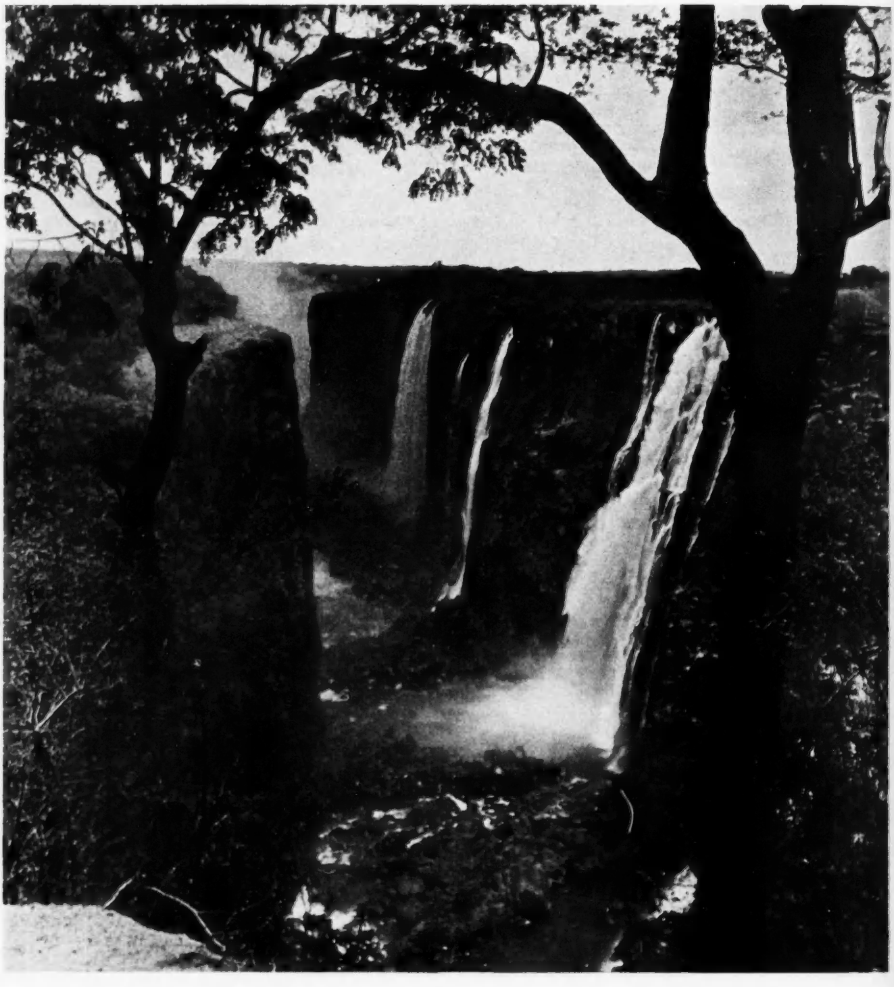
The cheap power supply will favour the industrial development of Livingstone, and if sufficient progress is made the hydro-electric scheme will be expanded.

The Victoria Falls, the largest in the world, on the mighty Zambesi, are of indescribable beauty. Splendour, magnificence, grandeur, stupendousness—a mere collection of words—are totally inadequate to portray the wonder of the Falls; and even photographs and films can only hint at it. Americans who have seen them agree that they "beat Niagara to a frazzle".

The first white man to discover them was Dr David Livingstone, the explorer and missionary, who straightway named them after Queen Victoria. His excitement, when his native carriers led him there through the bush, must have been intense. Above the Falls the Zambesi is about a mile wide, increasing to a mile and a quarter as it goes over the edge, but below the Falls the river is never more than a hundred yards wide. This extraordinary phenomenon which adds so much to the beauty is explained in the following way. The whole torrent of water falls into a vast crevasse about 350 ft. deep, 50–100 yd. wide, and a mile and a quarter long. From this crevasse there is only one exit, through a narrow gorge facing the middle of the Falls. Here the water comes rushing through in a terrific boiling whirlpool, immensely deep. Imagine the whole of Oxford Street suddenly flooded with water from above, the only outlet being down Regent Street. Oxford Street is about a mile and a quarter long, and if you imagine its houses are 350 ft. high and its roadway 100 yd. wide, you have a model of the Victoria Falls.



The edge of the Fall is not an unbroken surface but is split up by numerous small islands which end in bastions of rock at the edge of the precipice. Photographs on pages 192 and 193 were taken in the dry season, for only then does the spray lessen enough to allow the floor of the crevasse to be seen. In the rainy season the right side of the crevasse is a solid wall of water as on page 191. The Falls are divided into three main parts. The Eastern Cataract, the most beautiful part, extends for about half a mile and can be seen from the side or from the opposite bank of the crevasse. The Main Falls are in the middle and can be seen from the "Rain Forest" on the opposite bank. Here there is a continuous downpour through the dense tropical creepers and palm-trees. In the wet season the Main

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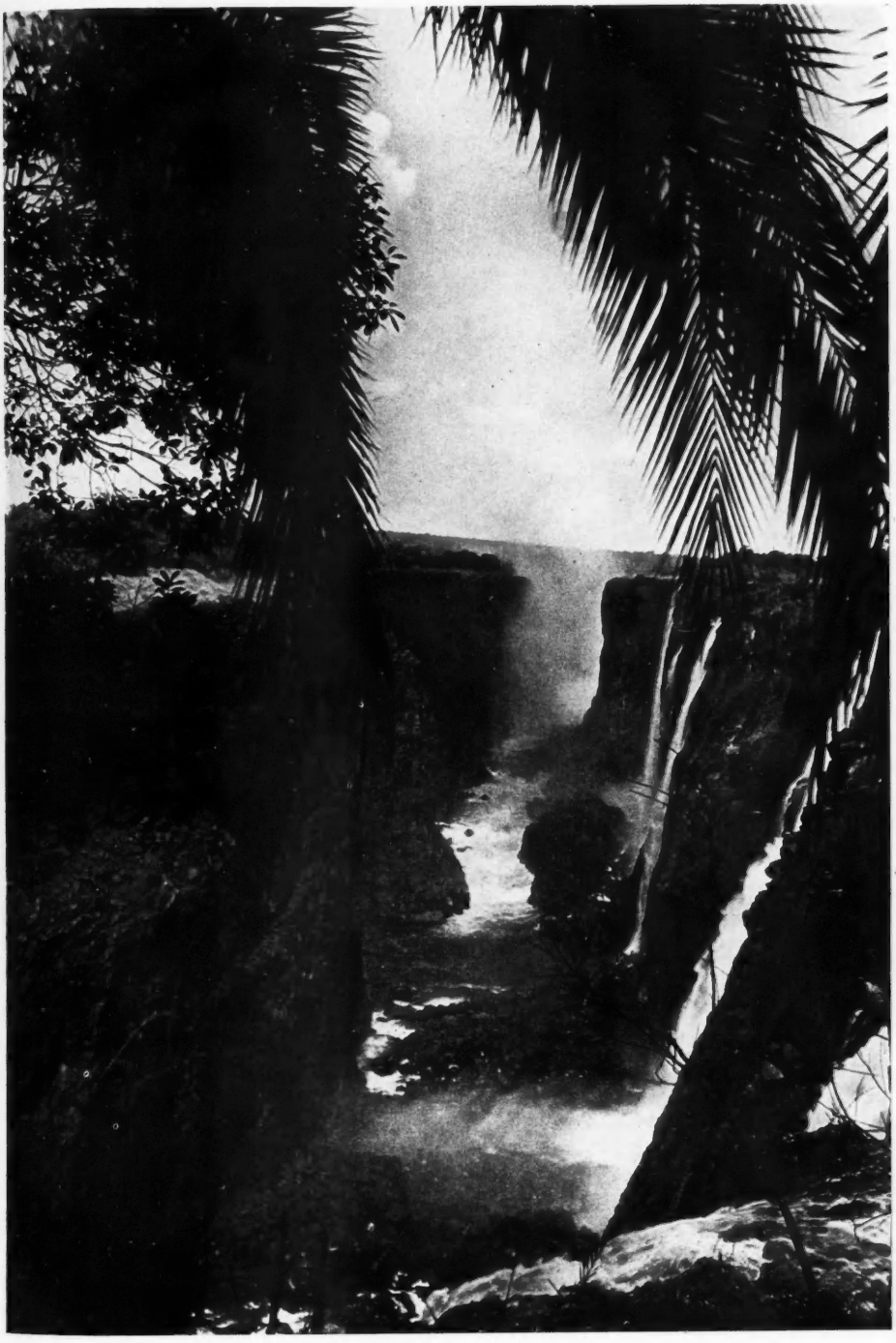
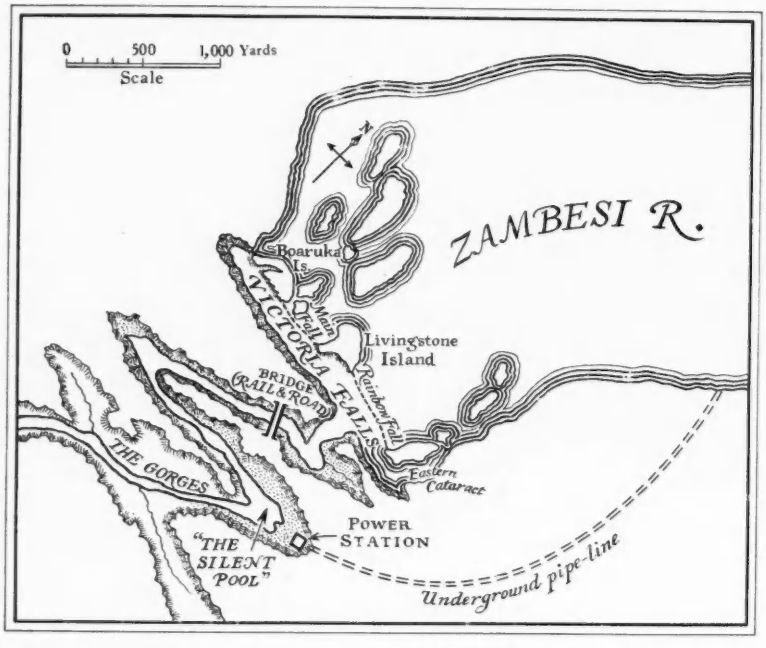


Falls can hardly be seen for spray and only from the air can one see the whole extent of the Falls at one time.

At the West end is the Devil's Cataract. The water cascades down a steep rocky slope for 50 ft. and then drops sheer into the crevasse. At the edge of the Devil's Cataract stands a statue of Livingstone, and in the distance lies the island where he carved his initials on a tree.

In the dry season it is possible to paddle across the top of the Falls to Livingstone Island and stand on the edge of the precipice. Native fishermen come here with their primitive nets and stand waist deep in the rushing water and, fortunately for them, crocodiles seem instinctively to keep away from the edge of the Falls.



I went off the beaten track to take these photographs. To take the picture on page 193 I had to wade through the water and jump from rock to rock to a patch of earth on the edge of the precipice. Here I wedged myself between the stems of two palm-trees and balanced on one leg and one elbow until the sun came from behind the clouds. In taking two of the others I was drenched to the skin. Wind blew the spray towards me in sudden gusts and I had to wipe the lens continually.

One of the most wonderful things about the Falls is the formation of rainbows where light strikes the tall column of spray. At the Eastern Cataract and Devil's Cataract there are nearly always fine rainbows far down the crevasse whenever the sun is shining, and sometimes a rainbow can be seen from the railway bridge

just below the Falls. But at full moon the beauty of the rainbows is beyond description. The lunar rainbow colours are quite different, the soft pastel shades standing out clearly against the jet-black wall of the gorge. The falling water is silvered as it roars down into the unlighted depths.

The Falls by moonlight, showing the lunar rainbow

To *the Editor*

Dear Sir,

Have you room for two suggestions inspired by Mr F. H. Mackintosh's interesting article "England is Sinking" which appeared in your April number?

It seems to me that the risk of flooding in the tidal zone of the Thames has been enhanced in comparatively recent years by human activity. Brown's *Nautical Almanack* for 1914 gave the mean rise of the spring tide at London Bridge as 20¾ ft. while in the corresponding 1935 publication the figure was increased to 22¼ ft. Presumably this increase, if real, is to be attributed to the dredging and general improvement of the river channel.

As is well known, water is obtained from the sand and chalk under London by means of deep borings and the level of the great underground reservoir has been lowered—I believe something like 100 ft. This depth of strata previously saturated with water, might easily shrink from 4–6 ft. on drying, and the resulting surface subsidence would be of widespread character and include the low-lying river banks.

FRANK ADCOCK, D.Sc.
Sen. Sci. Officer, Nat. Physical Lab.

New Hearts for Old

By JOHN YUDKIN

(*Dr Yudkin has already contributed several times to* Discovery. *In* New Hearts for Old *he describes some remarkable modern operations on the heart. For our next number he has written an article of great importance on the abuses of patent medicines.*)

EVERY organ in the body must have an adequate blood supply if it is to continue to function properly. If its blood supply is completely cut off, it will die. The heart, which is really a specialized muscle, needs an efficient blood supply just like any other muscle, in order to bring it oxygen and foodstuffs and to remove waste products. The wall of the heart is too thick for these substances simply to diffuse through it from the blood which is always flowing through its chambers. It is therefore provided with a system of blood vessels through which blood is pumped, as it is to all the other organs of the body, by the action of the heart itself. The vessels which bring this blood to the heart are the two coronary arteries and the flow of blood along these is exquisitely adjusted to its demands. During exercise or exertion, the heart has more work to do, and immediately the amount of blood flowing through the coronary arteries is increased. During severe exercise, nearly three pints of blood may be passing through these two small vessels in a single minute—a quarter of the total amount of the blood in the body.

The Disease of Age

The coronary arteries, like the other arteries of the body, are liable to the disease of age—arteriosclerosis. They become harder and thicker and their originally smooth walls become roughened and coated with fatty material. So that it is not surprising that in many older people with artery disease, the heart muscle gradually finds it more and more difficult to obtain a sufficient quantity of blood, particularly if the demands on the heart are increased by bodily exercise.

Warning

Whenever the life of the heart muscle—and so of the individual—is endangered by the inadequacy of its blood supply, nature's warning is sounded—a severe pain is experienced. This is the well-known condition of angina pectoris. A man may notice as he runs for the train one morning that he is suddenly stricken with a sharp pain: he feels as if his chest is gripped in a vice. He stands rooted to the spot, anxious and pale—after a short time, if he has heeded the warning and rested, the pain passes off. Many patients will say that they get the attack after a definite amount of bodily exercise; for example, after they have walked two hundred yards up the hill as they go to their work in the morning. In others, the disease progresses to such an extent that the patient cannot perform the slightest degree of exercise without an anginal attack—they become completely bedridden. And at any stage, coronary thrombosis may occur. The diseased coronary vessels become completely occluded by the clotting of the blood within it and the heart stops beating. Fourteen thousand men and women die of angina pectoris or coronary thrombosis in England each year. And it is interesting that disease of the coronary arteries is a particularly common cause of death amongst professional workers. For example, one out of every seven doctors dies of the results of diseased heart arteries.

What can be done?

What can be done to treat the disease? Naturally, curtailment of the activities of the patient, making him lead a careful life, will impose less work on his heart and there will be less chance of its suffering from a shortage of blood. And there are drugs which he can take which make the coronary vessels dilate for a short while so that the blood flow through them is improved. More recently, operations have been devised in which certain nerves going to the heart have been cut. The agonizing pain of angina ceases since the nervous pathway carrying pain sensations to the conscious mind are destroyed. But there are many physicians who criticize such operations on the ground that the pain is a warning signal and tells the patient when his heart is doing more than it should. Moreover, none of these treatments effects a cure—none really solves the problem of the defective blood supply to the heart. If only it were possible to give the heart new blood vessels...

The creation of new blood channels in the body is not unknown. It has been found possible, for example, to recreate veins for the removal of blood from a liver in which the venous drainage is impaired by cirrhosis. An operation is performed in which the thin smooth coverings of the liver and of the adjacent inner wall of the abdomen are removed. Veins gradually develop between the roughened surfaces and the blood from the liver returns to the heart along these new paths. If new veins can be produced in this way, would it not be possible to encourage the growth of new arteries to the heart from other organs?

Animal experiments carried out in this country by Dr Laurence O'Shaughnessy and in the United States by Dr Claude S. Beck proved that this is possible. The circulation in the coronary arteries of dogs was gradually shut off by silver bands which were tightened in successive operations. At the same time, other tissues in the chest were closely applied to the heart, the thin covering sac of which had been partially removed. Dr Beck found it possible by this means completely to close one of the coronary arteries and a large branch of the second, leaving only 15% of the normal coronary blood supply, without any obvious impairment in the health or activity of the dogs. In Dr O'Shaughnessy's experiments, greyhounds in which a main branch of one coronary artery had been closed were able to chase the electric hare for the full course of 525 yds. without any difficulty.

Examination of the dogs some time later showed that there were many well-developed arteries running to the heart from the surrounding tissues and that the heart muscle was perfectly normal. These results then were extremely successful—a heart need not die even if most of its normal blood supply is cut off. But these were dogs' hearts. Would the same result in the human heart? Surely no one would have the courage to operate on the heart of a living human being—remove its lining sheath and apply other tissues to the raw heart surface.

The New Operation

But so convinced was Dr Beck by the results of his animal experiments that he decided to apply the operation to patients ill from coronary disease and early in 1935, at the Lakeside Hospital, Cleveland, Ohio, the first human heart was submitted to the new operation. The patient, Joseph Krchmar, forty-eight years of age, had his first attack of angina nine years before he entered hospital. He had continued his work as a miner for a few years, but his attacks became so frequent that he gave up his work and took up farming. Shortly afterwards, however, his attacks began to recur and soon he was rarely free from them. For the last ten days before he came to hospital he had been confined to bed.

The Patient Chooses

The possibilities and risks of the proposed operation were explained to him, but knowing the agony of the disease and knowing that he might become a bed-

ridden invalid, liable at any time to sudden death, he chose the hope of the unknown to the certainty of the known. On 13 February 1935 the operation was performed. A portion of his chest muscles was brought into the chest and applied to the roughened surface of the heart. The operation was an amazing success. The patient was completely cured and in a few months he was able to work as a gardener without the slightest recurrence of the pain. Encouraged by this success, Dr Beck operated on several other cases. One of these was a man of fifty-five, a machinist, who for two and a half years had had frequent attacks of angina pectoris so that he had to give up his work. After the operation he was able to resume his work and a year later was still completely free from attacks.

Another Angina Case Cured

Dr O'Shaughnessy, working at the Cardio-vascular Clinic at Lambeth Hospital, has developed a slightly different mode of operation called cardio-omentopexy. He uses the omentum from the abdomen for supplying the new blood vessels. This tissue, a thin membrane, very well supplied with blood vessels, is brought into the chest through a hole made in the diaphragm. He has so far operated on twenty cases, the same number as has been reported by Dr Beck. Amongst his patients was a woman of sixty-five who for twelve years had suffered from attacks of angina. The disease progressed steadily until for the last eighteen months she had to spend most of the time in bed, unable even to wash herself. She underwent the operation on 16 October 1936. By April 1937 she was completely recovered and was able to climb stairs and go shopping without the slightest difficulty or pain. Another patient was a paper seller, a woman of forty-four, who had collapsed in the streets with pain under the heart. Even after four months in bed in hospital, she still had a considerable degree of heart failure. She gradually improved during the next three months, and although the condition of her heart was still very poor, she was sufficiently well recovered to be able to withstand the operation. A few months later her heart condition was almost normal and she was able to get about for several hours a day with no symptoms whatever.

Risks of the Operation

Of course, the operation is a very serious and difficult one, and it is not surprising that it has resulted in the deaths of a number of the patients undergoing it. But it must be remembered that most of these were very ill indeed and would only have lived a very short while as complete invalids and in almost constant pain. In fact, two of the cases in the Lambeth Hospital died there a few days before operation was due. It was with these very ill patients naturally that Dr Beck and Dr O'Shaughnessy felt justified in suggesting the then unknown risks of operation. These patients were eager to take such risks—they felt that life in their condition was anyhow not worth living. But now that the operation has been so successfully carried out in twenty-seven of the total of forty gravely ill patients so far treated, it will in future certainly be used for many more less severe cases. In such patients, undergoing the operation in the early stages of the disease, the risks will probably not be greater than those of any of the commoner surgical operations.

With hearts given a new blood supply in this way, an extraordinary advance has been made in the fight against disease. We are only witnessing the beginning of this advance and it is really too early to say how effective it will be. But the possibilities are immense—heart disease is the chief killer of men and at last it seems as if diseased, worn-out hearts can be strengthened and revitalized and the body given a new lease of life.

"Frozen Air"

By Michael Lorant

(*Mr Lorant describes a new scientific film. The film itself deals with experiments which will be familiar to many readers of* Discovery; *but it is interesting to be reminded of them in such a striking way.*)

THIS is the first scientific film made by UFA, Berlin. First of all the film shows in an ingenious way how the molecules of which all bodies are composed are unceasingly in motion, and how this motion grows faster as temperature rises, and slower as temperature falls. At the extremely low temperature of $-273{\cdot}16°$ C. (absolute zero) all molecular motion would cease entirely. With this in mind we can more easily understand what happens as cold becomes more and more intense.

After a short review of the methods of lowering temperature by means of cooling mixtures, quick evaporation, and the refrigeration principle of Karl von Linde, the film illustrates the properties of liquid air by a number of striking experiments. These show that marked changes occur in the properties of all bodies when they are placed in liquid air—that is, at a temperature of $-190°$ C. Eggs become as hard as stone, much harder indeed than when they are boiled; rubber loses its elasticity; a bell made of lead emits a metallic sound, and, by the use of the right shaped mould even a bell of mercury can be cast.

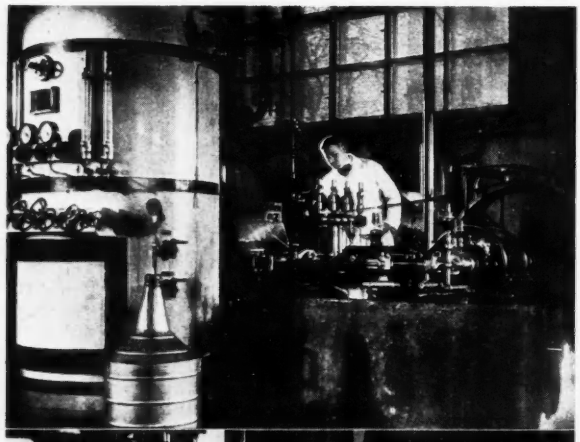
Next we are shown some curious properties of liquid oxygen, most striking of which is its magnetic character. By the use of a powerful electromagnet a piece of solid oxygen can be lifted out of its container and suspended in mid-air.

In technology, oxygen, which is one of the strongest promoters of combustion, is used in the liquid state as an explosive.

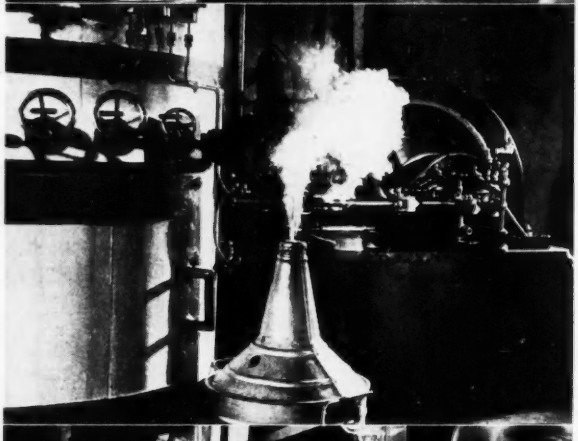
At $-190°$ C. nitrogen liquefies—a fact that led to a method for the recovery of nitrogen from the atmosphere, and thus assured our supply of agricultural fertilizers.

At $-246°$ C. neon liquefies. When reconverted into gas neon is used for filling those familiar red advertising tubes now seen everywhere.

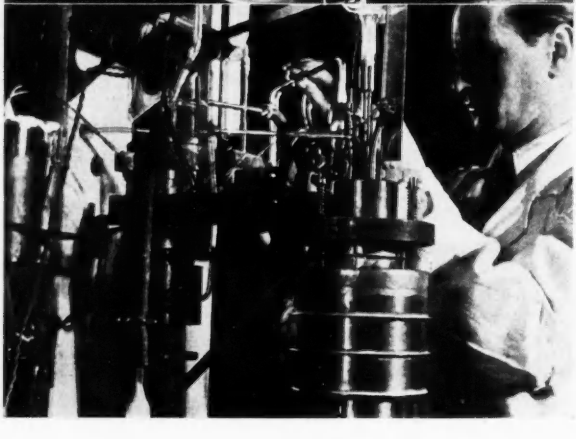
At $-253°$ C. hydrogen liquefies. Finally comes the lowest point on the temperature scale shown by the film, $-269°$ C., the temperature at which the inert gas helium liquefies. Although 1 million cubic centimetres of air contains only 5 cubic centimetres of helium, the use of technological cooling processes would provide one possibility of recovering helium from the air for the filling of airships.



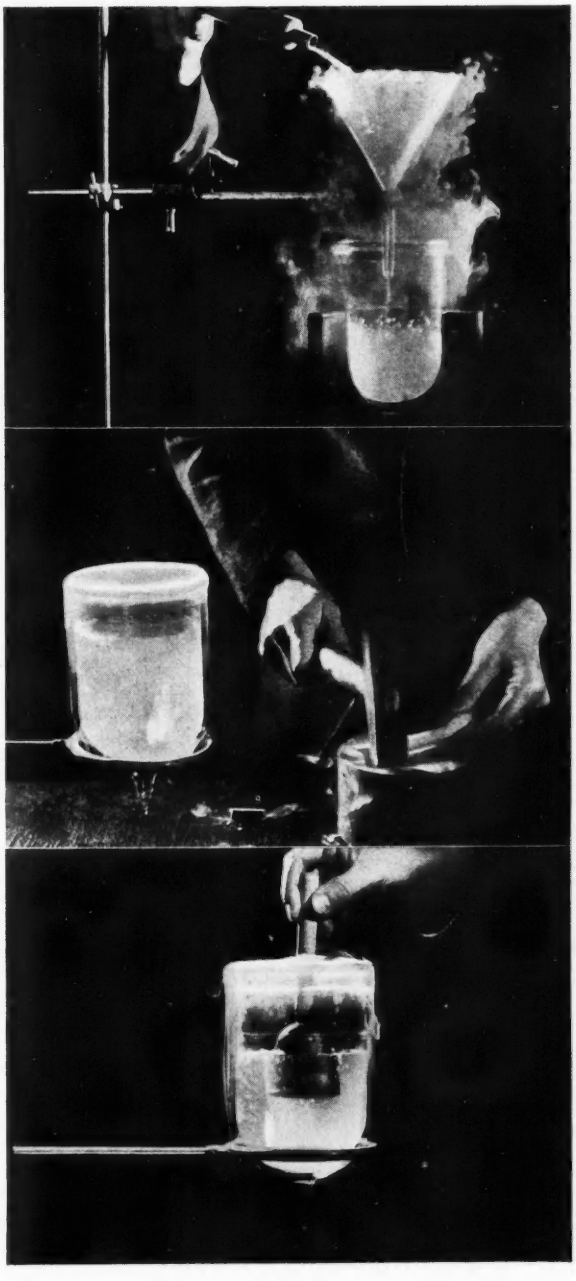
1
Machine for the liquefaction of air, invented by Karl von Linde.



2
In the foreground is a collecting receptacle from which the liquid air is volatilizing.



3
A nearer view of Linde's machine.

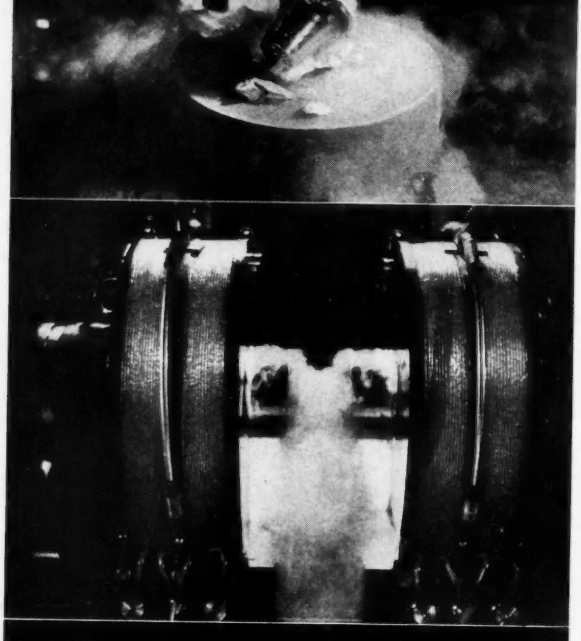


4
Liquid air can be filtered and runs through filtering paper like water.

5
Rubber loses its elasticity in liquid air, at a temperature of $-190°$ C.

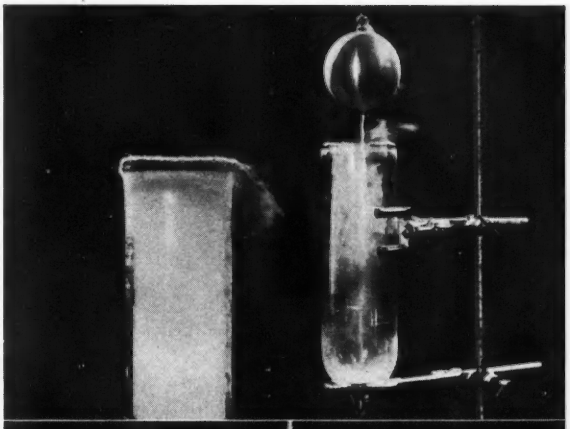
6
A leaden bell is cooled in liquid air, until it reaches a temperature of $-190°$ C.

7
Casting a bell of mercury that when rung emits a firm, resonant tone.

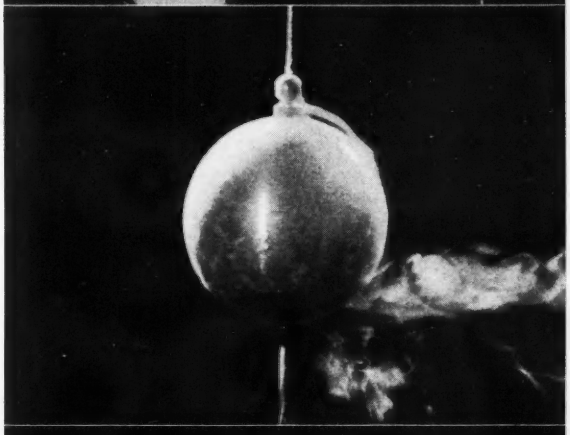


8
Liquid oxygen (−183° C.) is magnetic and floats free in air between the two poles of an electromagnet.

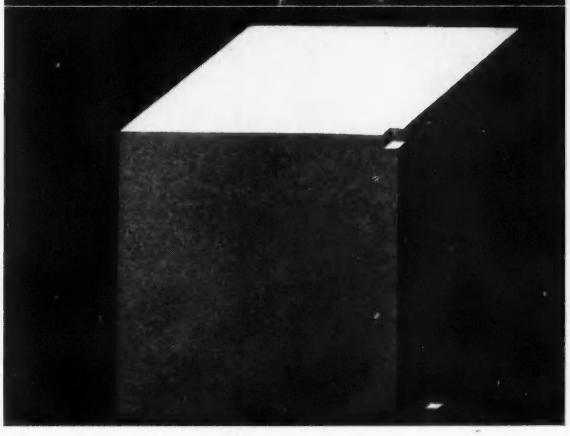
9
Neon is recovered from the air by liquefaction at −246° C.



10
If one cools a solid metal ball in liquid hydrogen (−253° C.), the air in the vicinity of the ball will keep on liquefying until the temperature of the ball has risen to −190° C.



11
A cloud of liquid air follows the ball.



12
One cubic metre of air (equal to 1 million cubic centimetres of air) contains 5 cubic centimetres of the rare and precious helium gas.

A Kangaroo That Climbs Trees

By Ewen K. Patterson

The kangaroo is undoubtedly the best known of Australian animals, being familiar, as a Zoo animal or in pictures, to millions of people who have never visited Australia.

A quaint creature that hops on its hind legs and carries its young in a bag-like pouch, especially developed for the purpose —that is what the kangaroo is, as probably everyone knows.

But not so well known is the fact that Australia also has a kangaroo which actually climbs trees! This remarkable monkey-like animal is among the rarest in the world, being found only in the little-known wilds of North Queensland.

Until recent times it was almost universally believed in Australia that there were monkeys in North Queensland. From time to time many strange stories were told by prospectors and others, who had penetrated the wilds, that they had seen queer kinds of monkeys in the trees—monkeys of types unknown elsewhere in the world. So numerous and frequent were the stories that many people were led to believe that there were monkeys in these wilds.

But thorough exploration has revealed that this is not so. Real monkeys are not found anywhere in Australia. The animals that were mistaken for monkeys were tree-climbing kangaroos—strange creatures, found nowhere else in the world, which are far more interesting than any monkey, and are among the most remarkable of the world's arboreal animals.

Superficially this animal does resemble a monkey in some respects when seen from a distance. The adult attains a height of between 3 ft. and 3 ft. 6 in., and its slim body is covered with a thick fur, reddish brown or brownish grey in colour. Its head, which is rather small for its body, has pointed ears, a long sharp nose, and two dark eyes. The animal has a pair of short forelegs, while its hindlegs are much shorter and smaller than those of the ordinary kangaroo.

One of the animal's most remarkable features is its enormous tail, which is very thick and ranges from 3 to 4 ft. in length, often being longer than the rest of the body.

Unlike the monkey, the kangaroo does not use its tail to hang by; it is employed merely as a balancing organ, and, except when the animal is climbing, it is always carried curled inwards between the legs.

The kangaroo lives in the uppermost branches of the tallest trees; it is an extraordinary climber and can ascend a tree as rapidly as any monkey. It is amazing, too, from what heights the animal can jump to the ground without injury. I have seen the marsupials leap from trees to the ground 50 and 60 ft. below, and, without a check, they bounded away into the bush. Such leaps would kill, or at any rate seriously injure, man or any other animal.

The kangaroo remains in the tops of the trees during the daytime, and will not descend unless disturbed. But at the first sign of danger it drops to the ground, and is away in a flash.

The animal feeds at night on berries, grass-tips, and wild fruits. The female has the customary pouch on the abdomen in which she carries her baby. The baby is born in the usual way, but in a very immature condition, being only about an inch long, blind, naked and entirely devoid of fur. Immediately after birth it is transferred by the mother to her pouch, where the infant's mouth at once closes on a teat, which then swells, holding the baby in the pouch. The little one obtains its milk food

from the teat, from which it cannot be removed. Any attempted removal invariably results in its death. The baby is carried by the mother in her pouch until it is about eight or nine months old, when it is able to move about and fend for itself. From time to time the baby leaves the pouch to nibble grass and to play with other young kangaroos, but it never goes far away from its mother, seeking refuge again in her pouch at the first sign of danger. The little animal actually dives into the pouch head-first and turns a complete somersault, ending with its head at the opening.

This remarkable tree-dweller of Australia might reasonably be described as a combination of kangaroo and monkey, and it is, without a doubt, one of the fastest animals in the world, both at climbing trees and running along the ground.

The kangaroo's chief enemies are the bush aborigines, who regard the animal as a great delicacy. To obtain the marsupials the natives are, of course, compelled to climb trees, and in this capacity they are experts, being regarded as the swiftest tree-climbing humans in the world.

When a native wants to climb a tree he simply obtains a length of lawyer-cane—an exceedingly strong vine which grows profusely in the bush. This is cleverly used as a support for the climbing native's body. Sometimes it is used round the tree trunk and round his body, but more often the vine is put round the tree only, the native holding both ends in his hands. The vine is then jerked upwards in stages, and the native gradually walks up the tree by its aid.

It is amazing the speed and ease with which some of the natives can ascend big trees by this simple method. Invariably, too, when climbing they carry a spear or two held between their teeth for killing the kangaroo they are chasing.

But attacking a kangaroo in a tree-top is not easy work, and at times it is dangerous. It is generally difficult to get close enough to it to use a spear, and when at bay the animal invariably puts up a fight, using its sharp teeth and claws viciously. Many natives have been severely wounded in this manner.

Supersonic Waves are Death to Silkworm Parasites

By H. Courtney Bryson

It is well known that the frequency of sound waves in air audible to the human ear ranges from 16 to 20,000 cycles per sec., this range decreasing with age, especially with regard to high notes. For example, a large number of old people—and some younger ones as well—cannot hear the squeak of a bat, the pitch of its note being extremely high.

The sound spectrum appreciated by animals is considerably wider than that perceptible by human beings. Whistles for dogs may be obtained with a pitch well over 20,000 cycles per sec. which produce no effect upon the human ear, but are plainly heard by the dog, which will run to its master at the sound—to the astonishment of onlookers not in the secret.

Above 20,000 cycles the waves in air are known as supersonic, and are generally

artificially produced by the mechanical oscillations of a piezo electric current under the influence of a rapidly alternating electric field or by the periodic contraction and extension of iron or nickel in an oscillating electric field.

They may also be produced mechanically by causing a thin jet of gas moving with a velocity greater than that of sound to hit a small cavity in the jet. The very high energy and short wave length of supersonic vibrations have led to their application in degassing liquids, precipitating fogs and smoke as well as producing them, emulsifying two immiscible liquids, homogenizing photographic emulsions, and for local heating of affected parts in medical practice.

From Japan comes news of a method utilizing these interesting vibrations, which in one year has already saved the country one million pounds sterling. Silkworms suffer from a verminous parasite called *Crossocosmia sericariae* which destroys thousands of millions of cocoons annually. After many years of laborious research work by the Japanese Imperial Agricultural Research Station, a very simple method has been evolved for the complete destruction of the parasite without damaging the host in any way.

The cocoons which are affected are sorted out, and, when 4 or 5 days old, immersed in water and submitted to supersonic wave bombardment for 3 min. The parasites are too big and tough to be actually killed by these waves, but are rendered so uncomfortable that they withdraw from the spiracles to which they habitually attach themselves into the body of the worm in an effort to escape. Here they quickly die of suffocation. The method appears so ingenious as to savour of one of the curious problems propounded by schoolboys to vex their fathers, but it is nevertheless now rapidly in course of being adopted by the whole of the Japanese silk industry. Some of the earlier work on the subject may be found described in the quaintly named *Tyo-ompa ni yora Kassan-Cisei-kyoso no Kujo-ho mi tsuite* by Yagi.

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The Dreaming Mind

By R. L. MÉGROZ

I. The Dreams of Savages

(*Mr Mégroz raises some most interesting and controversial questions about dreams. Since this subject is not yet scientifically established,* Discovery *cannot accept responsibility for his views.*)

THE study of savage mentality by anthropologists, though scarcely more than a century old and less than that as a science, has led to increasing attention to the dreams of savages, which already last century were seen to provide many ideas that become religious beliefs. Anthropology last century was definitely materialistic and the student of savage mentality who compared savages' dreams with religious beliefs intended usually to show the unreality of the objects of belief.

The demons and other spirits that populate the other-worlds of religions were traced, as Edward Clodd traced them, to the dreaming mind of the unsophisticated savage, who does not readily discriminate between what belongs to his dreams and what is "real", i.e. perceived by his waking senses. Clodd noted especially the common belief of savages in the living reality of dead people that they saw in dreams. In this way dreams of the dead can be regarded as the source of certain forms of ancestor worship and of ideas of a spirit world. Such dream imagery to men like Clodd consisted merely of "vain" fantasies, and the thought of the savage was too readily regarded as a mixture of ignorance and superstition.

What we may call the pre-Freudian view of savage mentality was ably presented by Sir Edward Tylor in *Primitive Culture*, which can still be read at almost any library. In his view "the doctrine of dreams, attributed as they are by the lower and middle races to spiritual intercourse, belongs in so far rather to religion than to magic. But oneiromancy, the art of taking omens from dreams by analogical interpretation, has its place here. Of the leading principle of such explanation, no better types could be chosen than the details and interpretations of Joseph's dreams (Genesis xxxvii, xl, xli) of the sheaves and the sun and moon and eleven stars, of the vine and the basket of meats, of the lean and fat kine, and the thin and full corn-ears." He was quite prepared to welcome examples of a rational element in the primitive thought, such as the belief of the Kamchadals that to dream of lice or dogs betokened a visit of Russian travellers. This kind of "Mother Bridget" wisdom was the most that the Victorian anthropologist could find in the mentality of "inferior" peoples, and while noting it, Tylor goes on to qualify the observation by noting that "the Zulus, experience having taught them the fallacy of expecting direct fulfilment of dreams, have in some cases tried to mend matters by rushing to the other extreme. If they dream of a sick man that he is dead, and they see the earth poured into the grave, and hear the funeral lamentation, and see all his things destroyed, then they say, 'Because we have dreamt of his death he will not die.' But if they dream of a wedding dance, it is a sign of a funeral. So the Maoris hold that a kinsman dreamt of as dying will recover, but to see him well is a sign of death. Both races thus work out, by the same crooked logic that guided our own ancestors, that 'dreams go by contraries'."

If you don't like this narrow Victorian

view, there is some entertainment in the thought of what the Freudian psychology, its materialistic successor, has done to show that in the deepest emotional sense, dreams do indeed go by contraries and often reveal wishes or fears that the conscious mind of the dreamer will not face. Much valuable work in anthropology has been done by psychologists who have traced in savage customs the external forms taken by dream wishes and fears. I have not the space now to review the ideas involved in the "complexes", but any book on the principles of psycho-analysis would explain them. But universal "complexes", such as the attitude of a son to his father or to his mother-in-law, which will deeply influence the nature of his dreams, are now realized to be unconscious motives that shape the social customs of the tribe, resulting for instance in the privileges and restrictions of a chief, or in the taboos surrounding sexual behaviour.

But the modern anthropology, based on Freudian theories of dreams, may also be limiting the study of savage dreaming too closely, so that elements in their dream life which do not support theories of psycho-analysis are brushed aside. Thus savage beliefs in ghosts and omens, and their cults based upon dream divination, are supposed to have no more significance than was given to them by the older anthropologists, apart from any influence they may have in forming social customs. Yet the anthropologists, collecting their data, go on recording instances of savages claiming a supernormal power of perception in dreams. Such claims seem to be universal among savages as also among all the civilizations that have left a literature behind.

In a recent book of great interest—*The Dream in Primitive Cultures*—Dr J. S. Lincoln, a disciple of the eminent Dr Seligman, while reviewing social customs in the light of Freudian theories, records many examples of claims to divination by dreams. For example, he examines the dreams of the American Navayo Indians, and their ceremonies, and finds the evidence he wants in support of the Freudian theory of an Œdipus complex, but does not comment upon the fact that nine of the collected dreams were prophetic. (Seven others were of death; three about being caught in dangerous places or slipping down; thirteen about being chased or attacked by animal or man.) Some of those prophetic dreams anticipated a coming disaster, such as an uncommon storm or a serious epidemic causing many deaths. Others foretold the death of a relative. A man named Hasteen Hal dreamed that he saw "a white aeroplane" that landed near his tent. "I didn't believe in aeroplanes in those days," he said, "and I hadn't even seen an automobile. I hadn't even heard of aeroplanes at the time. When I woke up I told the Indians of my dream, but they wouldn't believe me. I said if it is true, we shall hear about planes. Since then I have been to Gallup (the nearest town to the reservation) and have seen lots of white planes just as in the dream."

If such beliefs in the power of the mind to dream things that otherwise the dreamer could not know are nothing but ignorant superstition, it is indeed strange how the records of similar experiences continued to be made through all the stages of civilization, and to-day receive serious attention from intelligent people. There are other queer experiences also of similarly widespread nature which I hope to describe in later articles. Meanwhile, instead of quoting from another anthropologist, here is an account supplied by my friend Mr C. T. Stoneham, an author who has been much in contact with African natives. It concerns the Masai, whose country is now in Kenya, and their chief's vision of the aeroplane as a "giant bird" may be compared with the dream of the Navayo already quoted.

It is an historical fact that the British had no trouble with this warlike people when colonizing the country. The reason, according to the local story, which Mr Stoneham heard on the spot, was a warning given to his people by Lyanasha, the greatest witch-

doctor chief, or hereditary Lybon, the Masai ever had. He died about the middle of last century at more than 100 years of age. Before dying he told his people: "I see a great snake stretching right across the country of the Masai. Huge birds will fly over, and the shadow of their wings will be on the veld. These things will the white men bring." He warned them against shedding white blood. The "Great Snake" was recognized by the chiefs when they allowed the British to build the Uganda railway unmolested. Big air liners now cross Masai-land.

This story belongs to a large class of similar records, many of which will be remembered by readers. Thus in *The Spirit-Ridden Konde*, D. R. Mackenzie tells us of a native prophetic vision. The people of the Konde, which is in the Lake Nyasa region, believe that the foreteller, the *unkunguluka* —who is dedicated to his cult or profession —has acquired the power to see in dreams all danger to the chief or the community. "The verb *kukunguluka*," says the author, "means to go or fall down; to sink deep; and the *unkunguluka* is the man who goes down, in dreams, to the underworld, to obtain there the word that he is to deliver to the chief."

Omitting all but the essential detail here, the German defeat at Karonga, in September 1914, had been clearly foretold by Njuli and Mwandisi, two seers or wizards living near the lake shore. The Germans knew nothing of this prophecy, but they found it impossible to obtain any local carriers to help them, and most of the carriers they recruited had to be found among the Basango, to the north. It was also foretold that the Germans would evacuate Nen Langenburg without fighting, which actually happened.

Evidently we may usefully consider the dreams of savages for ideas outside the scope of psycho-analysis.

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